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THE USE OF THE PANORAMIC CAMERA IN TOPOGRAPHIC SURVEYING

WITH NOTES ON THE

APPLICATION OF PHOTOGRAMMETRY TO AERIAL SURVEYS

BY

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By Alfred H. Brooks.

The plate camera has been used for many years in topographic surveying in the United States and Canada, as well as in many European countries, and since 1910 J. W. Bagley, a topographic engineer of the United States Geological Survey, has been employing the panoramic film camera in conjunction with the plane table in surveys in Alaska. Mr. Bagley has devised some new instruments and methods and has proved conclusively that the panoramic camera is extremely valuable in certain kinds of topographic work. Some of the results of his phototopographic surveys are presented in the maps accompanying this bulletin. These maps give conclusive evidence of the refinements that are made possible by the use of that instrument.

The methods and instruments here described have thus far been used only in Alaska, but they promise to have a wider application in topographic surveys; hence this bulletin has been prepared. As the camera is used in conjunction with the plane table the bulletin includes also a brief account of the uses of the plane table.

Mr. Bagley shows clearly that the field cost of surveys made by the use of the panoramic camera and plane table is far lower than that of surveys made by the plane table alone, and though the compilation of the field data in the office is more laborious the final cost of the completed map is nevertheless lower. The methods here described are especially applicable to regions where the field season is short, the field cost high, and the climatic conditions adverse to topographic work.

In view of the present interest in aerial surveys, Mr. Bagley has appended to the volume a discussion of the use of the camera in such work. This discussion, which is largely based on French treatises, presents briefly the principles and some of the methods of photogrammetry in its application to aerial surveys. The subject needs further study and experimentation.

THE USE OF THE PANORAMIC CAMERA IN TOPOGRAPHIC SURVEYING.

By JAMES W. BAGLEY.

INTRODUCTION.

The purpose of this bulletin is to describe the field and office instruments used in topographic surveys of certain parts of Alaska in which the ordinary plane-table instruments were supplemented by the panoramic camera, to show the way they were used, and to present some of the results obtained.

In view of the increasing importance of photography in surveying and the rapid strides that are being made in the art of navigating air craft it has seemed desirable to include also some notes on the application of photogrammetry to aerial surveys. These notes have been gathered chiefly from the publications of the two eminent French authors Laussedat and Saconney, whose volumes are mentioned elsewhere in the text. Though it is impracticable to treat this subject here in even an approximately complete manner, it is hoped that the matter presented will interest many to whom the original sources are not readily available. In acknowledging the credit that is due to Laussedat and Saconney, the writer wishes to state that though the methods they suggest seem practicable he has not had the opportunity to test them. It is hoped that by the inclusion of even so brief a summary a stimulus may be given to aerial surveying, either directly or by drawing attention to what is being done in this field in other countries.

Photographic methods have been employed in various forms for many years by surveyors in foreign countries, but the use of the camera in surveys in the United States was, until the commencement by the Geological Survey of the work in Alaska here discussed, confined to certain surveys carried out by officers of the United States Coast and Geodetic Survey, in connection with the survey and location of the boundary between the United States and Canada by the International Boundary Commission, to a survey of the Pribilof Islands, and to a few other surveys of less importance. The slight use of the camera in topographic surveying in the United States is due largely to the character and size of our part of the North American Continent. The progress of settlement in extending

westward over enormous areas of timbered and prairie lands of relatively small relief called for a development in surveying methods which brought out the plane table as the most serviceable instrument for the work. As no better means were available, thought and energy were concentrated upon adding to and improving the plane table. The consequence was that a relatively large body of topographers became highly trained in this method of surveying, so that when, in more recent years, surveys were extended farther into the mountainous regions of the West not only was little thought given to taking up other methods, but there was, in fact, little need for other devices, because of the skill and rapidity with which the surveys could be executed by use of the plane table. This was true of a very large part of the West that has been mapped. There were exceptions, however, which must have inspired the topographers with thoughts of improved methods of work, for in the desert mountains of the Southwest and in the northern Rockies there are large areas of rugged and bare ranges which consist of an almost bewildering number of peaks, spurs, pinnacles, saddles, and slopes—details which must be located on the map in order that the topography may be properly represented. The Grand Canyon of the Colorado is a field so tedious to survey with the plane table, so extensive in length, in relief, and in wealth of features, that it alone, in the writer's opinion, would justify the employment of the camera in its topographic survey.

Alaska contains a greater proportion of mountains favorable for phototopographic surveying than the United States proper, and the method here described was there first tried out. Most of the surveys made in Alaska have been of either exploratory or reconnaissance character, and travel has been accomplished almost wholly by the use of pack animals and boats. In all these surveys, owing to the expense and limited means of transportation, it was necessary to reduce the camp equipment and supplies to that amount which careful estimation and experience proved to be needful. The great weight of photographic plates presented an obstacle to the use of plate cameras which, in the opinion of the writer, scarcely left a sufficient margin of gain to warrant their adoption for these surveys. Plate cameras also carried the objection of a field of view so narrow that seven or eight exposures were necessary to photograph the entire horizon.

Where extensive surveys are to be carried across mountains and valleys account must be taken of the variety of topographic forms likely to be encountered, and the method for the surveys should be chosen accordingly. Of all methods in which transportation must be overland that of the plane table is most serviceable for many varieties of topography. But the panoramic camera enables the

topographer to retain the plane table and at the same time to employ photography in its simplest and most satisfactory form, for the one may be used to supplement the other to whatever extent the type of country demands. It also appears certain that a combination of the two methods will form a surveying equipment superior to either alone if it is effected without loss to either. These are the chief reasons why the panoramic camera gave promise for improvement in topographic surveying.

The use of the panoramic camera is not confined to surveys where a small scale is employed, but in some mountainous areas the instrument is adaptable to surveys on a scale of a mile to the inch or even larger, and in general the gain on the side of speed increases as the scale increases.

In testing a new method for topographic surveying it was necessary to keep pace with the general trend toward better quality in topographic maps. In the results here discussed the writer is satisfied that in control, location and representation of features, and expression—all the essential factors—improvement has been made. In attempting to reduce the results to a basis for satisfactory comparison with results from other methods it has been found that conditions of work vary so greatly in different fields and the personal equation plays so important a part in topographic surveying that it was impracticable to present a completely comprehensive table, but Table 1 (p. 16) gives a comparison of results obtained by the writer with the plane table alone and with the plane table supplemented by the panoramic camera. A large number of items have been embraced in this table in order that it may, in a measure, permit comparisons by others who may wish to make them with data of their own.

The expense of equipping topographic parties and of producing contoured maps is great, and much endeavor has been made to get the results more cheaply. In pursuing this object it is necessary to keep certain recognized standards in view lest unfortunate errors lead to a weakening of the framework of the map. Whatever improvement may be made in gathering the information necessary to map topographic forms, there will remain the necessity of control in base maps, and there seems to be little chance for reduction in the work as now executed to obtain that control. Already some very noteworthy beginnings have been made in the use of aerial photography for topographic surveys, yet in this work, too, control must be established by exact measurement on the ground in many places. Such considerations lead to the conclusion that though we may expect photography and other means to reduce the cost of topographic surveys and to lessen the time required for them, yet it is doubtful whether the processes of those surveys can be simplified.

The writer wishes to acknowledge the aid received from the Bureau of Standards, which was essential to the construction of a panoramic camera of the precision desired for surveying, and especially to express his appreciation of the advice received from Messrs. P. G. Nutting and E. D. Tillyer, formerly of that bureau. Acknowledgments are also due to Mr. W. H. Boyd, of the Geological Survey of Canada, for much information that led to improvements in office instruments; to Mr. C. H. Au, a mechanical engineer, of Washington, D. C.; and to Mr. F. H. Moffit, of the United States Geological Survey, for miscellaneous assistance in photography.

HISTORY OF THE USE OF PHOTOGRAPHY IN TOPOGRAPHIC SURVEYING.

The value of perspectives to engineering had been recognized many years before the advent of the photographic camera, and when in 1839 the facts of the discoveries that had been made by Niepce and Daguerre were presented to the French Chamber of Deputies the aid which photography promised to bring to the construction of topographic maps was forecast. It is noteworthy that even before Laussedat had published the results of his first experiments with cameras that had fixed objectives Martens, another Frenchman, had devised a cylindrical camera that employed a revolving objective. To Laussedat, however, falls the credit for the first practical work of adapting the camera to surveying. His work, begun in 1849 under the engineer corps of the French Army, was carried through many years of great activity. Accounts of his progress published from year to year established him at the head of topographic engineers in the use of photography. In 1901 part 1 of the second volume of his treatise on instruments and methods of surveying placed much of his material on photography in convenient form for use by others, and this was followed by part 2 in 1903.[1]

Though France led in this field it was not long before scientists in other European countries began to experiment with the camera. In Germany Meydenbaur was the leading spirit in adapting photographic methods to engineering needs. His work consisted of devising original methods of his own as well as of introducing those that had been developed in France. The interest which he and others aroused led to the employment of photography for a great variety of scientific purposes. One of the most significant developments was the adoption by the Prussian general staff of photography for military surveys. Before 1870 a corps had been organized and trained in photographic methods, and it assisted in the military operations of the Franco-Prussian campaigns.

[1] Laussedat, Aimé, Recherches sur les instruments, les méthodes et le dessin topographiques, Paris, Gauthier-Villars, pt. 1, 1901; pt. 2, 1903.

The first period of activity in applying photography to engineering practices is characterized by the development of the plate camera in connection with the theodolite. Instruments of considerable precision resulted, and these were mainly phototheodolites of various forms and arrangements. This period extends to about 1900. About that time E. Deville, surveyor general of Dominion lands, Canada, took up the idea of using stereoscopic photographs instead of single photographs. He experimented with a Wheatstone stereoscope, but abandoned these attempts on learning of the progress being made in the same direction by C. Pulfrich in Germany. Though the idea seems to have been first presented by Deville, Pulfrich [1] worked out a method of stereophotogrammetry which has probably had more influence in photographic engineering than all other devices since Laussedat's announcements. Pulfrich's method immediately engaged the attention of many engineers in Germany and Austria, with the result that his devices have there been elaborated and his methods employed in many branches of scientific work. The stereoautograph of Von Orel and, more indirectly, the optical instruments for aerial photography of Scheimpflug and Kammerer, in Austria, are notable evidences of the stimulus given to photographic engineering by Pulfrich.

The use of the camera in topographic mapping, though possibly more highly developed in France, Germany, and Austria, has by no means been confined to those countries. Porro, Paganini, and others in Italy and Thilé in Russia made early and profitable use of photography. Photographic surveys have been made in most of the European countries and in several of the American countries. Accurate data as to the extent of these surveys is lacking, but the total area of the North American Continent that has been mapped by the camera probably forms a considerable percentage of the total area of like surveys over the entire globe. The use of the camera in surveying on this continent is due primarily to the efforts and influence of E. Deville,[2] who in 1886 began systematic phototopographic surveys in western Canada. More than 30,000 square miles of territory has been mapped photographically by the Canadian Government bureaus, including the International Boundary Commission and the Geological Survey of Canada. The regions in Canada where the camera has been used are the rugged portions of the western and northwestern provinces. Deville's general type of camera

[1] Pulfrich's method of stereophotogrammetry is described by Otto Lemberger (Stereophotographic surveying: Eng. News, vol. 69, pp. 602-612, 1913). The principles of this method are given in a very excellent treatise by J. A. Flemer (Phototopographic methods and instruments, New York, John Wiley & Sons, 1906). See also Dock, Hans, Photogrammetrie und Stereophotogrammetrie: Sammlung Göschen, Berlin and Leipzig, 1913. This work is profusely illustrated with views of forms of phototheodolites and stereoscopic instruments used to make measurements on negatives and to reduce the data to the map.

[2] Deville, E., Photographic surveying, including the elements of descriptive geometry and perspective, Ottawa, Canada. This book is a standard publication on the subject.

designed for use in rugged mountains, and a light theodolite, each of which may be mounted on a single tripod, have been employed in the Canadian surveys.

Definite information as to the progress made with phototopographic surveys in other American countries is lacking, but reports indicate that photographic methods have been employed in surveys in the Andes and in Argentina. As most of the South American and Central American states contain considerable mountainous areas it is the writer's opinion that photography would prove a valuable aid in surveys of those countries.

In the United States phototopographic surveys, which were commenced by officers of the United States Coast and Geodetic Survey [1] in connection with the International Boundary Commission, have since been continued until at present somewhat more than 12,000 square miles has been so mapped. Two classes of surveys were included in this work—reconnaissance surveys on a small scale and detailed surveys on a scale of approximately a mile to the inch. The camera used is a modification of Deville's, and it is supplemented by a separate theodolite which may be set up on a common tripod.

A topographic survey of the island of Tutuila, Samoa, has lately been completed by the Hydrographic Office of the Navy Department. For these surveys a plate camera of Deville's general type was employed to obtain stereoscopic views, and the negatives were worked up in the office at Washington by means of a stereocomparator. It is reported that the method gave satisfactory results.

The panoramic camera was first employed in topographic surveying in Alaska by C. W. Wright [2] in 1904, and he was associated in this work with his brother, F. E. Wright. Both were at that time members of the staff of the United States Geological Survey engaged in geologic work in Alaska. The instruments now in use are developments from that beginning. The first panoramic cameras used by Mr. Wright were improvised from commercial instruments by fitting level bubbles and arranging internal scales which formed images upon the negatives. Although these cameras were not constructed primarily for the purpose of surveying, Mr. Wright reports that satisfactory results were obtained with them.

In 1907 Mr. Wright had a new camera made according to specifications which he had drawn up, but it did not become available for use for that season, and soon afterward this work was interrupted

[1] Flemer, J. A., Phototopographic methods and instruments: U. S. Coast and Geodetic Survey Rept. for 1897, pts. 1 and 2, Appendix 10, pp. 619–735, 1898.

[2] Wright, C. W., The panoramic camera applied to phototopographic work: Am. Inst. Min. Eng. Trans., vol. 38, pp. 482–497, 1908.

by his transfer to another field. Little was then done with the panoramic camera until the writer had an opportunity to use it, to a small extent, in 1910. His experience at that time was convincing as to the merit of the panoramic camera, and since then the extent of its employment in Alaska surveys has steadily increased until at present four instruments have been constructed for that purpose, so that two parties may each be equipped with two cameras when engaged in favorable fields.

With the rapid development of the airplane and dirigible balloon in European countries came a corresponding development of aerial photography for military reconnaissances and an awakening to the value of aerial photographs for surveys other than those of a military character.[1] French engineers indorse the aerial methods of photographic surveying as both rapid and economical, and the same opinions seem to be held by engineers of other countries who have had the opportunity of drawing careful comparisons between the various methods of surveying. In the opinion of the writer aerial photography will in the future not only have a prominent part in military reconnaissances in this country, but quite certainly will also have a direct and important bearing on the practices of civil engineering. The notes on the application of photogrammetry to aerial surveys appended to this volume indicate procedures that may be useful in pursuing the development of aerial surveying.

Available records concerning the panoramic camera fail to indicate that the earlier patterns were actually employed in topographic surveying, although it is probable that the "cylindrographe" designed by Moëssard was used to a small extent, for it was constructed for that purpose. This instrument, to judge from drawings of it, seems to have been well conceived and constructed, so that it is difficult to understand why it did not find more favor among topographic engineers in France. The only explanation that occurs to the writer for this failure to attract the attention of those interested in phototopographic methods is that probably when the camera was brought out the films available were much inferior to those procurable at the present time. Besides Moëssard's camera a very novel instrument, called a "planchette photographique," devised by Chevallier in 1858, deserves mention. This camera recorded the entire horizon on a horizontal plate, the light rays being turned at right angles by means of a prism. The "périgraphe" of Mangin is a similar instrument, which permits an instantaneous exposure of the entire horizon, the image being likewise recorded on a flat plate.

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[1] Saconney, J. T., Métrophotographie, Paris, 1913. This volume contains very complete material on the use of aerial photography in surveying and presents it in concise and admirable form.

COMPARISON OF THE PANORAMIC CAMERA WITH OTHER METHODS OF SURVEYING.

PLANE TABLE.

In reconnaissance surveys of mountainous regions the factor which ordinarily has the greatest influence upon the progress of the survey is the time required for travel between stations. The most striking feature of the panoramic camera is that it greatly reduces the time necessary to be spent at stations. Only about one-fourth of the time required at stations by the plane-table method is necessary with the panoramic camera. The advantage gained by this reduction, however, is largely offset by the dead work of travel. Furthermore, the rate of progress is often governed more by the speed of the pack train than by the time necessary to occupy stations. It is true that a topographer who is skillful in the use of the plane table can generally keep his survey abreast of the movements of his pack train while covering a strip of territory from 10 to 20 miles wide. In doing so he will commonly occupy a single station a day and seldom more than two stations a day. If his rate of progress is 4 miles a day and the average width of country he covers is 15 miles he must sketch from 30 to 60 square miles from each station. In most mountains the average radius of work from a station will be the same for the camera as for the plane table, for this limit is determined by the amount of detail necessary for the scale of the map and the panoramic cameras supply photographs which have the necessary range. Therefore, in surveys of this kind, as indicated in Table 1, the final advantage which is gained from the use of the panoramic camera comes from an increase in the number of stations rather than from an increase of area surveyed per day, and the result of this increase in stations is an improvement in the map.

In surveys of relatively small areas on a larger scale the time required for traveling between stations, though of considerable amount, does not have so great importance as it does in reconnaissance surveys, because the stations are placed closer together, and consequently a large number can be occupied in a working day. In surveys of this class the value of the panoramic camera will depend more on the average contents of the photographs. It is obvious that the usefulness of photographs increases with the number of points that can be located from them, so that the more intricate the topographic forms the greater will be the value of the photographs. In contrast to the resulting gain in reconnaissance surveys the value of the method in surveys on the larger scale is in an increased output. The extent of this increase, compared with plane-table surveying, will depend on the character of the mountains and the scale of the map. The largest scale of surveys in which the panoramic camera has been

used was 1: 48,000. This is by no means the limit for its use, for horizontal angles can be turned from the photographs with all the precision necessary for a scale as large as 2 or 3 inches to the mile. The limit of the camera's usefulness will be determined by the degree of accuracy necessary in determining elevations—that is, roughly, by the contour interval.

Table 1 gives a summary of results obtained from the use of the plane table and from the plane table supplemented by the panoramic camera. It should be understood that the figures show results of work in a region where wages and cost of provisions and transportation are very high—probably higher than in any other civilized quarter of the globe—so due allowance should be made for this condition.

The Eagle River and Tanana surveys were executed by the plane-table method alone. In the Bonnifield survey a panoramic camera was employed to a small extent. For the Port Valdez and Moose Pass surveys a single camera was employed and in the Broad Pass and Nelchina-Susitna surveys two cameras were used.

The gain from the use of a panoramic camera is expressed in columns 6, 7, and 8, as well as in the columns of costs, because the advantage lies as much in increasing the number of stations, and thereby limiting the range of field to be covered at each station, as in a direct reduction of cost. The column of costs per square mile (9) should be read in connection with columns 3 and 5 in order that the influence of the weather and the cost of transportation to and from the field may be taken into account. In order to eliminate these two factors column 11 has been added. In arriving at the figures there shown only those percentages of the total costs which were chargeable to salaries on workdays, subsistence on workdays, equipment, and transportation in the field were used. The figures therefore represent only approximate unit costs of the various surveys and thus merely show the relative value of the panoramic camera in comparison with the plane table.

It will be seen that the relative cost of the Port Valdez survey is less than one-third that of the Eagle River survey. In order that these figures may not be misleading it is necessary to explain the conditions under which the surveys were made. Both of the districts are adjacent to the coast, and they presented similar difficulties to travel. The proportion of timbered areas is very much greater in the Eagle River district than in the Port Valdez district, and large glaciers cover much of the Port Valdez district. It would be a very difficult if not impossible task to equalize all the many factors that would have to be taken into account to reach a common basis for the two surveys, but by estimating roughly the effect of the timber and

ice and eliminating the expense of traverses necessary for both surveys the resulting ratio of costs was approximately three to four in favor of the Port Valdez. This result gives a ratio nearer that between the costs of the Moose Pass and the Eagle River surveys, which, the writer believes, indicates with a fair degree of accuracy the relative values of the two methods in country of average favorable type. The areas covered by the Eagle River and Moose Pass surveys show a difference in amount of timber. It has been estimated that this difference was about balanced by the increased cost of transportation for the Moose Pass survey, which was effected with pack horses, requiring the additional services of a packer. The Port Valdez and Moose Pass surveys were made with the aid of only one panoramic camera, and by the employment of an auxiliary camera a further reduction in cost could have been reasonably expected.

Column 12 has been included in the table to show the time spent in office work in the several surveys. Roughly, the figures indicate that the photographic method requires about one-fourth more time for the detail surveys and only slightly more for those of the smaller scale. In the photographic surveys a large portion of the contour sketching is done in the office, whereas in the plane-table surveys, especially those on the larger scale, the contours must be sketched on the ground. This difference accounts for the increased amount of office work necessary for photographic surveys. But where the difference in amount of field sketching involved in the two methods diminishes, we should expect a corresponding change in the relative time necessary for the completion of the office work, and as in surveys on the smaller scale the amount of field sketching in the two methods is more nearly equal, a smaller difference of time for the office work results.

PLATE CAMERA.

In reconnaissance expeditions, where extensive areas are to be surveyed, broad valleys of low relief are certain to constitute a considerable portion of the region. The camera alone may be inadequate to gather the data necessary to contour the slopes and to trace the drainage in these valleys. The plane table, having been continuously employed to establish the positions of the stations and other points of control, becomes immediately available for obtaining details which can be put on the sheet without the inconvenience of improvised control and with but slight delay in progress. The topographer who is prepared for both rugged and rolling country can pass from one to the other with all the advantage that both the plane table and the camera offer. This usefulness in all types of country is the chief point of superiority which the panoramic camera, combined with the plane table, has over methods of surveying in which plate cameras are used in combination with the theodolite.

Another advantage is the locative nature of the negatives, which, by supplying data for their own control, permit great freedom of movement in auxiliary cameras. This quality practically eliminates all uncertainty of the camera's position, whether or not the stations have been sighted in the plane-table scheme. It is only necessary that the panoramas include the required number of control points properly disposed around the horizon.

The third advantage is gained by the use of film cartridges instead of plates. The cartridge of four exposures packed in a waterproof case weighs 5 ounces. Three exposures complete the horizon, so that the cartridge has a scope of 480° with necessary overlap. In the prevailing type of plate camera used in surveying, nine plates would be required to embrace 480°. These would weigh 20 ounces packed, four times the weight of the film. Two hundred rolls of film, weighing less than 70 pounds, have been used during a season of about three months. The equivalent weight in glass plates is close to 300 pounds. Such an additional load would require a considerable increase in outlay for transportation.

The dependable accuracy of results in determining elevations from film negatives is indicated in Table 8 (p. 61). Doubt of the reliability of such determinations seems to have been the only argument against the use of the panoramic camera in topographic mapping. An allowance must be made for accuracy of measurement of films as compared with plates, and when the amount of this allowance has been determined a comparison can be made of the relative values of the panoramic camera and the plate camera. For the panoramic camera there is greater ease and rapidity in field operation, more freedom in selection of stations, marked reduction of weight in negatives, greater safety in the transportation and care of exposed and developed negatives, and increased facility in the office compilation. The plate camera has the sole advantage of supplying negatives that permit greater refinement in establishing elevations, a refinement which becomes necessary only in large-scale work that has a small contour interval. As this refinement would not be needed for general service maps on the smaller customary scales, there is no justification for the time and expense necessary to obtain it. The balance therefore is greatly in the favor of the panoramic camera.

STEREOPHOTOGRAMMETRY.

The attention which stereophotogrammetry is receiving demands a comparison of this method with that of the panoramic camera. In stereophotogrammetry the plate camera is employed to obtain stereoscopic views from points whose distance from each other is carefully measured. This distance is known as the base. In accordance with principles of descriptive geometry, instruments have been

constructed by means of which the field covered by such a pair of plate negatives can be rapidly converted to a map. The base and the focal distance for the negatives are known quantities from which the desired quantities, distances to points and differences of elevation, are obtained. Measurements are made upon the plates by means of microscopes and micrometers, which supply results with considerable precision. This application of stereoscopic photography is striking. The ingenuity manifested in the instruments of Pulfrich must command the respect of all who acquaint themselves with what he has done. The field which these instruments have opened or made more accessible to photography is wide and varied, and it is probable that work can be done with them which could not have been done without them. It is, however, as a means for general topographic surveying that the method concerns the present discussion. In this work there is no need to go beyond the single consideration of the base. In order that the stereoscopic negatives may have a considerable range the bases must be from 50 to 300 feet long. The kind of country in which it would be possible to select positions for stations where room could be found to lay out these bases is not ordinarily the kind in which photography is best adapted for topographic surveys. It is obvious that the pointed and commanding peaks, which offer the most advantageous positions for the camera, could not be occupied in stereophotogrammetry. Because of this fundamental feature it seems improbable that this method can be satisfactorily employed at the tops of rugged mountains.

AERIAL PHOTOGRAPHY.

It is not commonly realized that a photograph of a plane surface taken with a plate camera directed perpendicularly toward that plane is a map of the area which the photograph embraces. In other words, it is possible to use the camera to produce charts, in the form of negatives, of level ground, provided the camera can be placed in a position directly above the ground. Here the camera will merely be doing on a small scale what is done on a very much larger scale in map reduction by photography. It is essential that the lens give a true perspective and that the plane of this perspective be parallel to the plane of the ground or its angle of inclination be determinable. Upon this basis Theodore Scheimpflug,[1] of Vienna, devised a camera consisting of eight lenses arranged in such a manner that one of them is directed downward and the other seven lenses are disposed around the first with axes inclined at 45° to the optical axis of the central lens. The eight plates are exposed simultaneously. The

[1] Scheimpflug, Theodor, Die Herstellung von Karten und Plänen auf photographischem Wege: K. Akad. Wiss. Wien, Math.-naturw. Klasse, Sitzungsb., Band 116, Abt. 2-A, pp. 235–266, 1907. See also Kammerer, G., Th. Schiempflugs Landvermessung aus der Luft: Internat. Archiv Photogrammetrie, Band 3, Heft 3, pp. 196–226.

central negative, if parallel to the plane of the ground, is a correct chart of the ground it covers, but the seven inclined negatives are distorted charts which require correction in order that they may be joined to the central or true chart. To make this correction, Scheimpflug designed an optical instrument which he has called a photo-perspectograph. By means of this instrument photographs taken of the original inclined negatives fall into the plane of the central negative and supply extensions to that negative on the same scale.

The assumption thus far has been that the ground to be mapped is flat. For rolling and mountainous country the charts will be distorted or contain errors, whose amount will depend on the relief of the ground, the height at which the photographs were taken, and the angular range of the photographs. There is also the requirement of control, which must be supplied in every set of negatives in order to orient the charts and give them scales.

Without experience with a method so different in nature from the methods commonly used in surveying, it is not possible to draw the limits of its possible future field, but there are certain hindrances which are liable to delay, if not prevent, the general use of this type of photography. The most serious of these hindrances are the expense and hazards incurred. The airplane or the dirigible balloon would be required to reap the full benefits of this method, and the gain or loss in its use would depend upon the cost of operating the aerial vehicle. The farther the field of the surveys lies from facilities for transportation by water and rail and the rougher the country of that field, the less useful is the method at present. Its greatest usefulness will most probably be in military surveys and in topographic surveys of relatively flat regions where man-built structures are dense or where swamps and streams make surveying by older methods tedious and difficult.

FIELD INSTRUMENTS.

PHOTOGRAPHIC EQUIPMENT.

PANORAMIC CAMERA.

GENERAL FEATURES.

The panoramic camera set up for use is shown in Plate III. The camera box is made of aluminum and is inclosed in a protecting frame of mahogany that is lined with felt. The top of the aluminum box is the reference plane for leveling and the vertical axis carrying the lens is placed perpendicular to this plane. The circular film guides are adjusted so that when the film is in position for exposure all elements will be perpendicular to the level plane and hence parallel to the lens shaft. The horizontal scope of view is approximately 126°. A margin of 6° for each photograph allows ample range for

setting the camera by open sight and a sufficient overlap near the limits of the photograph for identification. The vertical scope is about 18° above the horizon and 26° below it. The greater range is given to the foreground in order to photograph all except precipitous slopes. Two seats at right angles to each other are arranged on the top of the box to receive a detached level bubble which permits a rapid adjustment for level. This adjustment is the only one that is necessary in using the camera. The camera is connected with the tripod by three leveling screws of a common pattern. The slit in the lens funnel is about 0.6 inch wide, a width which allows as much light to reach the film as the required accuracy in image will permit.

The lens is revolved by a spring, and the rate of revolution is regulated by detachable fans connected by gearing with the lens shaft. The fans which project outside the box require protection from sudden blasts of wind, and this is provided in the form of a cylindrical cap. The camera box has an opening at the back for the insertion of film cartridges. Both reels have free right and left motion, and they are equipped with adjustable friction brakes to hold the film closely in contact with the guides. Contact bars are placed in the back of the camera to aid further in holding the film accurately in place. The door, which is hung at the top, when closed forms a light tight covering for the lens and can be inclined at any desired angle to shade the lens from the sun at the time of exposure. It is necessary to use the wind guys when the wind affects the level bubble. A fine and strong fish line gives good results. The guys are anchored before the camera is finally leveled.

Before using the camera a test is made to ascertain whether the proper relation exists between the lens shaft, film guides, and level plane by exposing upon a field containing several prominent objects in the same horizontal plane with the lens. These objects should be placed or selected so as to be far enough away from the camera to make the test effective. If the line passing through these several images is straight the proper relation exists, but if not the correction must be made before taking the camera to the field.

The camera has been constructed in two sizes, one employing a 5-inch cartridge and the other a 6-inch cartridge. The equivalent focal length of the lens is about 5.4 inches, and for topographic surveying the image is perfect through a range of 30° from the optical axis. The 6-inch film is better adapted for use in precipitous country, for its vertical range is about 8° greater than that of the 5-inch film. The disadvantage lies in the extra expense and inconvenience of procuring special films differing from the regular stock sizes, such as the 5 by 4 inch twelve-exposure commercial film.

THE PANORAMIC CAMERA.

By placing the lens in the 5-inch camera a little below the center line part of the advantage gained in the 6-inch camera can be had, and on account of this possible arrangement the 5-inch camera is preferred.

LIGHT BAND.

Figure 1 shows graphically the elements that should determine the width of the light slit in the funnel. The focal plane is represented by the line *rx*. The lines *el* and *ad* represent parallel planes perpendicular to the optical axis, through the light slit and the optical center of the lens, respectively. The focal length of the lens (*ou*) is 138 millimeters and the distance *oh* is 80 millimeters. The diameter of the aperture at F 32, represented by *bc*, is 4.3 millimeters, and at F 6.3 (*ad*) it is 22 millimeters.

The minimum width of slit that will permit maximum illumination at the center of the light zone (*u*) when the aperture F 6.3 is used is

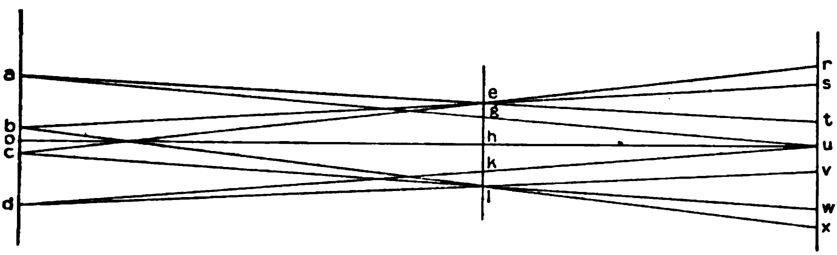


FIGURE 1.—Limits for light slit in panoramic camera.

shown by the lines *au* and *du*, crossing the plane of the funnel slit. This width (*gk*) is 8.6 millimeters. A source of error which must be considered is that caused by the use of a film in cylindrical form instead of a flat film. The maximum width of slit that can be used because of the cylindrical field is limited by the effect of the error in image ("softening") on both horizontal and vertical readings. Furthermore, the widest slit that the camera mechanism will conveniently allow is 15 millimeters. For a 15-millimeter slit the zone of full illumination will be 23 millimeters at the F 32 stop. The amount of this "softening," due to lack of focus, is shown for the edge of the zone in the following table:

TABLE 2.—*Amount of focus error due to light band.*

Stop.	Radius at focal plane (millimeter).	Effect on horizontal angles (minutes).	Effect on elevations at distance of 5 miles (feet).
6.3	0.04	1.0	8.0
11	.023	.57	4.3
32	.008	.20	1.5

We may therefore employ a light slit of any width between the limits 8.6 and 15 millimeters and maintain full aperture efficiency and introduce only negligible errors in image.

LENS SHAFT AND MOUNT.

In order to eliminate errors that would result from a failure to get the lens shaft accurately oriented with the film guides and the level plane, and from eccentricity in mounting the lens in the barrel, means for adjusting these positions might seem to be desirable. Experience in the construction of the cameras has shown, however, that the lens shaft can be placed with sufficient accuracy to make unnecessary, as well as undesirable, an adjusting mechanism which might prove a source of large and irregular errors, and the slight eccentricity that has resulted from the mounting of the lens can be obviated by turning the lens enough to throw the optical axis into the plane of the horizon.

LENS TEST.

Though there are doubtless other standard lenses that would adequately suit the purpose of the camera, the field work has not yet afforded an opportunity to make trials of more than one—the Zeiss Tessar series IIb. Tests of four of these lenses furnished reliable evidence of their uniformity of construction. The distortion is so slight as to be negligible. The table below gives the results of these tests, supplied by the Bureau of Standards.

TABLE 3.—*Results of tests of lenses.*

[Tests made by Bureau of Standards.]

Distance from lens axis (degrees).	Distance from lens axis in the focal plane (millimeters).	Distortion correction in millimeters for lens No.—			
		1	2	3	4
0	0	0.00	0.00	0.00	0.00
5	....	....	....	....	.00
10	24	.00	.00	.00	.00
15	37	− .02	.00	+ .02	− .03
20	50	− .06	.00	+ .04	− .05
25	64	− .11	− .06	+ .07	− .10
30	79	....	....	+ .02	− .00

Equivalent focal lengths: No. 1, 135.3 mm. No. 2, 138.5 mm. No. 3, 137.0 mm. No. 4, 136 mm.

A determination of the equivalent focal length of the lens must be made before the construction of the camera box is begun. The back focal length should also be ascertained. It is necessary for the circular film guides to be formed with a radius exactly equal to the equivalent focal length. The position of the lens in its collar can readily be fixed by simple measurement of the distance from the back lens surface to the film, this distance being equal to the determined back

focal length. A test of image definition can then be made by exposing the lens in this position and at different points nearer to and more distant from the film. An examination of greatly enlarged lantern images from the resulting negatives will disclose any discrepancy in the position selected.

The degree of accuracy obtainable in turning horizontal angles from photographs taken with a panoramic camera will depend on the focal length of the lens and the refinement of the means of making measurements. The open sight employed in turning angles permits a setting on a point within 0.01 inch of its true position. At the circumference of a circular arc having a radius of 5.4 inches (the focal length of the lens employed) the error of 0.01 inch in pointing corresponds to an angular value of 6½′.

INSTRUMENTS FOR DETERMINING DURATION OF EXPOSURES.

TYPES.

The many different styles of exposure meters and calculators in general use may be divided into three general types—(1) exposure meters, which are designed to measure the light intensity at the moment of exposure by means of sensitized substances; (2) exposure calculators, which are based on the computed intensities of the sun's light for given latitudes throughout the different seasons and for different hours of the day; and (3) the photometer type, which is designed to estimate the actinic value of the light reflected from the subject. The first type has only a moderate range of usefulness, and it is not adapted for landscape photography. The most troublesome feature of the second type is its unwieldiness. There are so many factors to be considered in arranging the scale that it seems impossible to design one for universal use. From the Equator to the polar regions the range of the intensity of the sun's light is too wide and differs too much from season to season and from hour to hour to make it possible to combine all the essential corrections in one compact design. It becomes necessary to employ different scales for different latitudes, and even in these scales there can be no provision for estimating the intensity of the light when the sun is very low and mists have risen to interfere with the light rays.

A simple and practical rule for timing exposures is given by F. H. Moffit. This rule requires the use, for a distant landscape of average brightness in fair weather, with F 16 stop, of the reciprocal of the sun's altitude in degrees to give the time in seconds or part of a second. Thus, if the sun is 20° high the time should be 1/20 second for F 16 stop in fair weather. Proper corrections should be made for cloudy weather and for different subjects and color screens.

Some of the statements made in reference to exposure may seem arbitrary to experienced photographers, and the writer realizes that

the rules here given are by no means final. The purpose has been to indicate to the surveyor who is inexperienced in photography a procedure that will permit him to obtain satisfactory results.

CALCULATOR.

The table of exposure times (Table 4) and diagrams of altitude curves (fig. 2) have been arranged by J. B. Mertie, of the Geological Survey, and are based on the principle that the intensity of the sun's light varies directly as the sine of the sun's altitude, as presented by Alves.[1] Upon this foundation a beginning for the table was obtained by exposing to find the proper time and stop for distant landscape under maximum illumination, and the remaining quantities followed in arithmetical ratio.

TABLE 4.—*Time (in seconds) of photographic exposures in fair weather, according to the sun's altitude.*

[For use with plates and films of speed designated by Burroughs, Wellcome & Co. as 1/6; Watkins, 180; Wynne, F 90. Use "Near" for less than 2 miles; "Distant," to 15 miles; "Very distant," over 15 miles.]

Sun's altitude.	Stop: U. S. / F.	2.5 / 6.3	4 / 8	8 / 11	16 / 16	32 / 22	64 / 32	128 / 45	256 / 64
48°–90°	Very distant	1/640	1/400	1/200	1/100	1/50	1/25	1/12	1/6
	Distant	1/320	1/200	1/100	1/50	1/25	1/12	1/6	1/3
	Near	1/160	1/100	1/50	1/25	1/12	1/6	1/3	2/3
30°–48°	Very distant	1/480	1/300	1/150	1/75	1/40	1/20	1/10	1/5
	Distant	1/240	1/150	1/75	1/40	1/20	1/10	1/5	2/5
	Near	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
22°–30°	Very distant	1/320	1/200	1/100	1/50	1/25	1/12	1/6	1/3
	Distant	1/160	1/160	1/50	1/25	1/12	1/6	1/3	2/3
	Near	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
15°–22°	Very distant	1/240	1/150	1/75	1/40	1/20	1/10	1/5	2/5
	Distant	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
	Near	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
11°–15°	Very distant	1/160	1/100	1/50	1/25	1/12	1/6	1/3	2/3
	Distant	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
	Near	1/40	1/25	1/12	1/6	1/3	2/3	1 1/3	2 2/3
7°–11°	Very distant	1/120	1/75	1/40	1/20	1/10	1/5	2/5	4/5
	Distant	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
	Near	1/30	1/20	1/10	1/5	2/5	4/5	1 3/5	3
5°–7°	Very distant	1/80	1/50	1/25	1/12	1/6	1/3	2/3	1 1/3
	Distant	1/40	1/25	1/12	1/6	1/3	2/3	1 1/3	2 2/3
	Near	1/20	1/12	1/6	1/3	2/3	1 1/3	2 2/3	5 1/3
3°–5°	Very distant	1/60	1/40	1/20	1/10	1/5	2/5	4/5	1 3/5
	Distant	1/30	1/20	1/10	1/5	2/5	4/5	1 3/5	3
	Near	1/15	1/10	1/5	2/5	4/5	1 3/5	3	6

[1] Alves, G. M., Outdoor exposures: Photominiature, vol. 5, No. 54, September, 1903.

Table 4 supplies any desired stop and time for the sun's altitude between 3° and 90°, when direct readings can be made for altitude. For simplicity in using the table it has been divided into zones which are broad toward the zenith and narrow near the horizon. A division of this kind is permissible, for the reason that the average quantities of time can be employed for a considerable change in the sun's altitude without introducing errors in results.

When the sun is not visible its altitude has to be determined in another way. Figure 2 is arranged for use in connection with the table when the sun is obscured. The diagrams are drawn for lati-

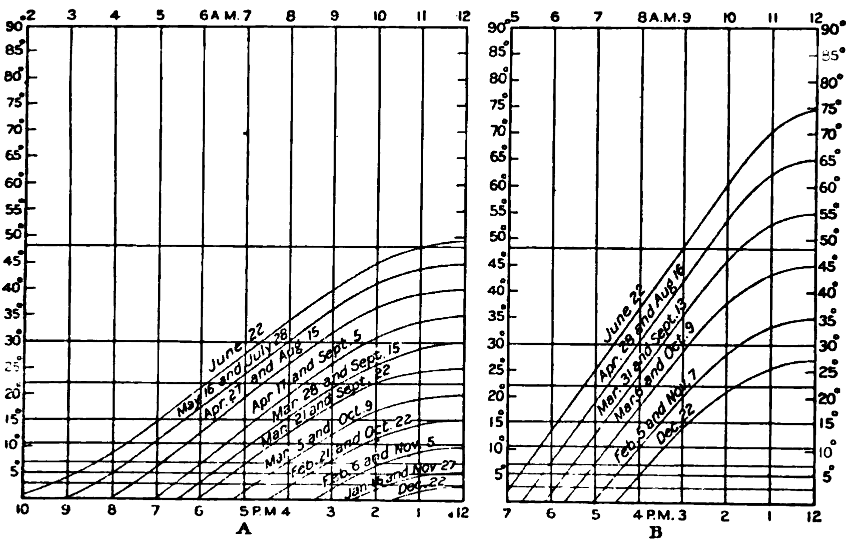


FIGURE 2.—Curves of sun's altitude. A, Latitude 39° N.; B, latitude 64° N.

tude 39° N. and 64° N. and they are appropriate for use within zones of 4° or 5° of latitude. For use in other latitude zones it is necessary to construct other series of curves. The curves were obtained from the formula

$$\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t \text{ . . . . } (1)$$

in which h = true altitude of sun, ϕ = latitude, δ = declination, t = hour angle.

It will be seen that the curves have an equal spacing at midday. This result was obtained by determining the dates at which the sun's altitude would have certain noon values. That is, the different values of the sun's declination, which would give certain fixed noon elevations, were calculated. In formula (1) the term cosine t becomes unity when $t=0$ (that is, at noon). The formula then can be converted into the form

$$\cos \delta = \sin h \cos \phi \pm \sin \phi \cos h \text{ . . . . } (2)$$

and in that form it is best suited for calculating with the minimum of labor the declination values above mentioned. When these declination values are known formula (1) can again be utilized in calculating the sun's altitude for the curves at the different hour angles.

PHOTOMETER.

The photometer type of exposure meter operates directly upon the subject, and theoretically it should supply the desired lighting factor more quickly and more accurately than any of the other devices, but it requires practice to get its "run" and to make the correction for individual vision. Compared with the calculators it has the advantage of possessing practically unlimited range and of measuring the light coming from the subject instead of calculating a general lighting condition. The practice of using a photometer and checking it with a calculator has given satisfactory results.

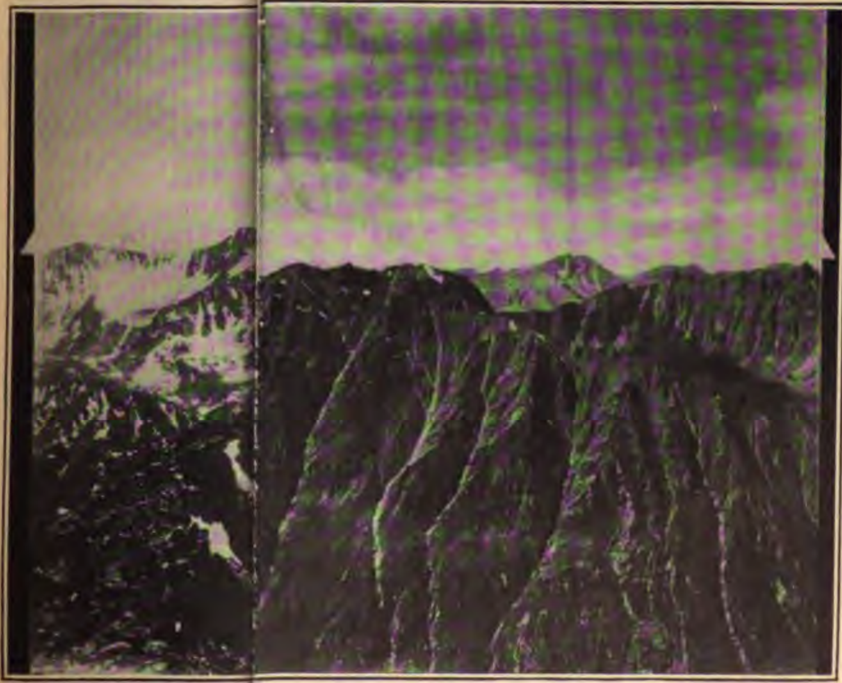
COLOR FILTERS.

A suitable color filter is a great aid in long-range landscape photography. The best color filter for photographic use is one that absorbs the rays of short wave length and allows the greatest portion of the remainder of the spectrum to pass through the lens. The light coming from distant objects, owing to its high percentage of the shorter wave lengths, acts with very much greater intensity than that from the nearer areas. The purpose of the filter is so to neutralize this stronger actinic light that the rays from all portions of the landscape may act sufficiently in a given time to produce fair images and to eliminate haze. The chart of curves shown in figure 3 is drawn from data furnished by the Bureau of Standards for different types of filters. Curves J, G, and L1 indicate efficient filters; E and P are of lower value; and L2 is almost worthless for topographic work.

The value of a proper filter is shown by the two photographs reproduced in Plate IV. The view shown in Plate IV, *A*, was taken without a filter early in the afternoon in June. Half an hour later the photograph shown in Plate IV, *B*, was taken, a filter of type G being used. This view faces approximately in the same direction as the preceding one, from the near knoll which is shown in Plate IV, *A*. The two photographs were taken from positions only 200 feet apart.

FILMS.

The films used should be of standard quality and sensitive to yellow and green light rays. Films are commonly labeled with a date after which they are not warranted to be free from deterioration. Experience with sealed films in Alaska has shown that they remain practically unaffected for several months beyond the date of the expiration of the guaranty. As this date is about one year from



the time the films were made it is safe to use them in a cool climate within 18 months from that time. It is doubtful whether this range of time would be greater than 12 months in a warm climate.

The number of film cartridges which should be taken for the field work will depend on the character of the survey and the area to be covered. A few extra cartridges should be included, in order that the supply may certainly be adequate. In reconnaissance surveys, which are made on a scale of 1:180,000, the area surveyed will very often be determined by the weather and the length of the season. In these surveys the probable number of unsuitable days is deducted from the number of days in the season, and an estimate is made on the basis of using three rolls of four exposures in a working day for each camera. This estimate provides for two stations a day for each camera. By area the estimate should be at the rate of three rolls for 40 square miles.

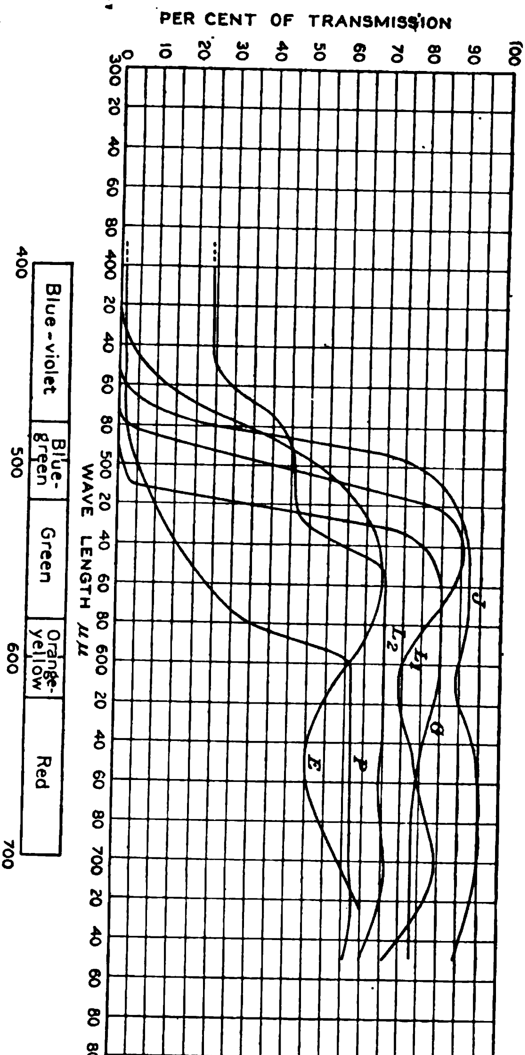


FIGURE 3.—Curves showing transmission of light through color filters of different types.

For surveys on a scale of 1 mile to the inch in country having little timber the number of rolls of film required will be approximately one to the square mile. Greater proportions of timber will lower the number of rolls required, for the reason that more of the area will be surveyed by traverses.

DEVELOPING OUTFIT.

TANK.

A developing outfit is indispensable in the field. By its use at times when regular field operations are rendered impossible, enough films can be developed to furnish thoroughly reliable tests of the exposures that have been made. Not only does the development eliminate the uncertainty as to the quality of the negatives being produced, but it greatly lessens the danger of injury to the films from moisture and light.

The form of developing outfit which, in the opinion of the writer, best meets the requirements is the developing tank, and the wooden changing box is discarded for a black sateen bag. This bag is really a "muff" of double cloth about 2½ feet long and 3 feet in circumference, which is supplied with elastic bands to draw the openings about the wrists when being used. The remaining parts consist of a spool and an apron. The complete kit includes changing-bag, metal tank, spool, and apron. The outfit takes little more space than the cylindrical tank, and the changing bag can be operated, after a little practice, with as much ease as the changing devices of other types. The bag affords far greater security against light during the work of changing, for it permits the use of the sense of touch, whereas the others must be manipulated "blindly." The apron is started on the spool before inserting it in the bag and the film is attached inside the bag and the winding completed there. Thus the film can be felt continually, whereas in the use of the wooden changing box no knowledge of the operation can be had until the lid is removed and the film, if uncovered, has been injured by light.

DEVELOPER.

The developer used should be that recommended by the manufacturers of the film, and it should be fresh, in order to insure no chemical change, or else it should be prepared according to standard formulas with pure chemicals by careful weighing. For field use, the prepared developers are much more convenient, but they are more expensive. The minimum quantity of developer taken for a survey should be sufficient to develop a few films every two or three weeks. With only a slight addition of weight, sufficient developer to develop all the films may be taken. Because of the saving in time it is convenient to use the developer in double strength. If this is desired, double the quantity should be available. The developer should be kept in moisture-proof packages.

TRAY FOR FIXING BATH.

The most convenient tray for the fixing bath is one made of paraffined canvas, about 16 inches long, 6 inches wide, and 4 inches deep. Such a tray may be folded into a small space for packing, and it will remain practically water-tight for several years. It should have loops at the top corners for the insertion of sticks, which serve to hold the walls upright.

FIXER.

Like the developer, the fixer should be fresh, pure, and packed in moisture-proof cases. That prepared and recommended by the producers of the film is likewise to be preferred. The hypo solution should be used with a hardener. The quantity to be taken should be determined at the rate of 1 pound of fixer to each eight rolls of film that are to be developed.

THERMOMETERS.

Long stirring thermometers with a flat disk at one end are the most convenient in form for tank use. Extra ones should be included in the equipment, to use in case of breakage. Thermometers of this type are sold by most dealers in photographic supplies.

DRYING CLIPS.

Drying clips of the spring and jaw type aid greatly in handling the films after development. A substitute for these can be readily made of sticks by splitting, notching, and tying them with thread. A clip or split stick should be fastened on each end of the film while it is drying.

PLANE TABLES.

FORMS.

The plane tables used in surveys in Alaska are of two patterns. For the more important stations and control a board 18 by 24 inches, set upon a strong tripod equipped with the Johnson head, is employed. No traverse lines except those of important water-courses, roads, etc., are executed for the small-scale reconnaissance maps, so the larger plane table suffices for the entire work. For larger-scale maps, such as those on a scale of an inch to the mile, a small board from 6 to 15 inches square supplements the larger table. The tripod head for this table is a smaller one, of the Johnson type. It is light and simple in mechanism. The Johnson head and both types of plane tables are fully described in the maker's catalogue, and therefore need no further mention here.

SHEETS.

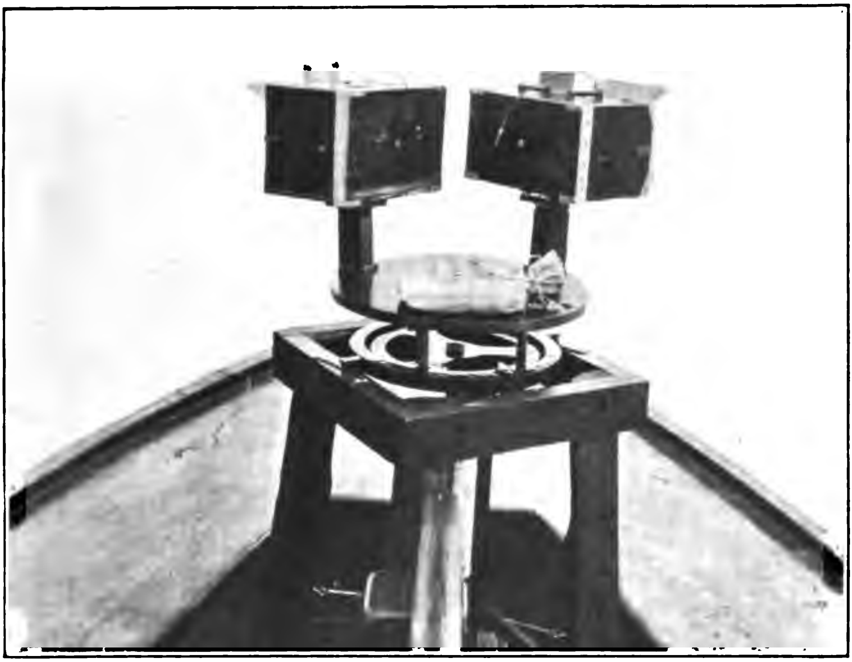
The triangulation scheme of control for the photographs may be drawn upon either double mounted paper or white opaque celluloid. The writer has found the celluloid preferable to the paper. Its one great advantage over paper is its freedom from injury by water. It holds pencil lines fairly well and is not more subject to contraction and expansion than paper. It must be guarded against fire, but so must paper.

Perhaps the most valuable recently developed auxiliary to plane-table work is the thin-sheeted frosted celluloid, which is rapidly taking the place of linen for making the locations of stations. It has the very great advantage of holding securely the original lines drawn from stations and thus furnishes permanent reference sheets for control. It frequently happens in extensive triangulation schemes that the positions of certain mountains, which may be used as stations, can not be accurately determined at the time they are being occupied. The transparent celluloid eliminates this difficulty, for by its use the determination of the true position of any station may be deferred until checks have been obtained from other stations more favorably situated. Indeed, it is possible to use these sheets on returning from the field to plot the entire triangulation scheme on a large sheet and thus to carry a check over the entire work of a season.

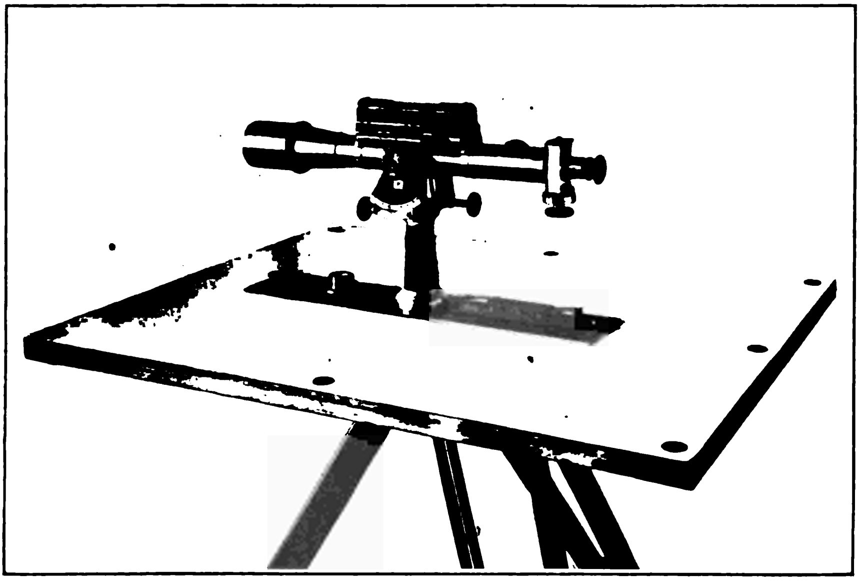
TELESCOPIC ALIDADE AND ATTACHMENTS.

The most necessary features in the telescopic alidade are rigid joints, objective efficiency, and lightness. The ruler should be about 15 inches long and the standard long enough to handle with ease. The circular arm should be graduated to read 30° at level in order to eliminate the necessity of positive and negative signs in the notes. Plate V, *B*, shows an instrument of recent design which properly meets the requirements. The auxiliary level bubble reduces the number of angular readings almost one-half, for when it has been adjusted for level position a single angular note upon a point completes the record.

An important attachment that seems not yet to have come into general use is the micrometer, which in certain uses may take the place of the stadia wires to considerable advantage. In form it is similar to that in use on refined terrestrial and astronomical instruments. Its advantage over stadia instruments lies in the fact that it permits a greater distance to be measured at a single reading, the limit of distance being determined solely by the effective range of the telescope. In operation the micrometer may be described as differing from stadia instruments by employing a fixed base and a movable wire instead of a graduated rod and fixed wires. Within certain limits the base may be of any desired length, as for a thousand



A. PANORAMIC CAMERAS SET UP ON GIMBAL-RING STAND ABOARD LAUNCH.



B. TELESCOPIC MICROMETER ALIDADE AND PLANE TABLE.

feet, between 5 and 10 feet; for a mile, between 25 and 50 feet; for 10 miles, 200 to 500 feet. This base may be marked by divisions on a regular stadia rod, by the distance between flags or cross bars attached to a standing tree, or by the distance between two trees or

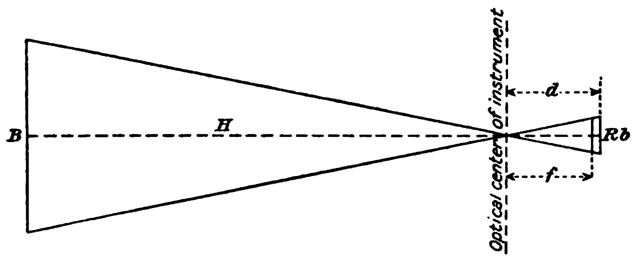


FIGURE 4.—Diagram showing mechanical principle of micrometer attachment for telescopic alidade.

rock cairns. The accuracy attainable with the micrometer for individual readings is from 1 in 100 to 1 in 500, and traverses can be executed with much greater accuracy due to compensating errors.

The formula for micrometer use can be deduced in a manner similar to that for stadia. In figure 4, let

B = base at right angles to line of sight on which readings are to be made.

H = distance of base from the optical center of the instrument.

d = perpendicular distance of plane of micrometer wire from the optical center of instrument (the wire moves in a plane perpendicular to the optical axis).

b = distance wire is moved by one revolution of micrometer.

R = number of revolutions of micrometer to cause wire to move the apparent length of base.

f = principal focal distance.

Then, from the similar triangles, we have

$$\mathrm{R}b : d = \mathrm{B} : \mathrm{H}, \text{ or } \mathrm{H} = \frac{\mathrm{B}d}{\mathrm{R}b} \qquad (1)$$

In formula (1) d varies with H, but from the relation

$$\frac{1}{f} = \frac{1}{\mathrm{H}} + \frac{1}{d}$$

we obtain a value

$$d = \frac{f\,\mathrm{H}}{\mathrm{H} - f}$$

which may be substituted in formula (1), with the result that we obtain a new formula:

$$\mathrm{H} = \frac{\mathrm{B}f}{\mathrm{R}b} + f \qquad (2)$$

in which all the values necessary for a solution for H can be readily determined.

As f is negligible, in comparison with distances usually measured, we may write

$$H=\frac{B}{R}C$$

in which C represents the micrometer constant.

C can be determined by tests on a known base over a carefully measured course, using the formula in the form

$$C=\frac{HR}{B}$$

The direction or bearing of the base must be known, and if it is other than at right angles to the line of sight its effective value practically becomes

$$B'=B \sin a \qquad (3)$$

a being the angle formed between the line of sight and the line of the base. The error introduced in obtaining formula (3) on the assumption of a right triangle is so slight, because of the small angle subtended by the base at the instrument, that it need not be considered in the calculation.

If the base stands at an elevation above or below that of the instrument the formula requires a further correction for difference in elevation.

The effective base then becomes

$$B''=B \sin a \cos V$$

where V is the vertical angle to the base. The general formula then takes the form

$$H=\frac{B \sin a \cos V}{R}C$$

The micrometer may also be used for stadia readings because the micrometer attachment customarily carries three fixed wires, to facilitate readings, besides the movable wire. It is only necessary to determine the point, as may be noted on the graduated drum, at which the fixed wire should stand to give the desired stadia interval between it and one of the fixed wires.

TRANSIT.

A light mountain transit is employed in surveys in Alaska to carry forward the triangulation. The transit further serves for observations of azimuth and latitude. A connecting attachment which receives the leveling screws makes its use possible on the plane-table tripod. The transit has a 4½-inch horizontal circle and an 8-inch telescope and can be read to 30″ of arc, so that the degree of accuracy attainable with it is about 1 in 5,000.

CHAINS.

A 100-foot steel tape is used to measure base lines. Through timber, where stadia traverses are impracticable, distances are measured with a linen tape or cord. This line is usually from 300 to 528 feet long, the length being made to conform with the scale graduations. Braided fish line of about one-tenth inch diameter is excellent material for the "chain." As this mode of obtaining measurements is usually employed over rough and obstructed courses, it becomes necessary to "tie in" such traverses at intervals not greater than 2 or 3 miles, and the tie points also serve as barometer checks.

ANEROID BAROMETER.

The aneroid barometer renders valuable service but must be used with caution. At least two daily checks are necessary besides the initial setting to obtain results reliable within liberal limits of error. The aneroid is doing its normal work if it registers the difference in elevation within 10 per cent. Furthermore, there are a great number of daily and atmospheric irregularities which, if they could be measured, would make the work of compensation too great to be profitable. The 2½-inch pocket barometer is in common use. The user should test his aneroid thoroughly to learn its peculiarities before forming the habit of using magnifying glasses and verniers for readings.

FIELD WORK.

SCALE OF SURVEYS.

The panoramic camera has been employed in surveys on field scales of 1:48,000 and 1:180,000. About 500 square miles have been mapped with it on the larger scale and about 22,000 square miles on the smaller scale. It has therefore been thought best to confine the descriptions largely to the work on the smaller scale and to add, as occasions arise, such notes as may be necessary to explain the differences of practice for the more detailed surveys.

HORIZONTAL CONTROL.

ACCURACY.

In general map control may be divided into two classes—(1) precise control, which places the map accurately in position on the earth's surface and at the same time connects all parts of the map together in a properly related system; and (2) a less precise control, which, though it supplies a practically correct and accurately oriented web of points and distances, does not attempt to determine those positions on the earth's surface with exactitude. Precise control is usually obtained independently of topographic surveys. It is relatively expensive but is necessary where great divisions of the earth are to be mapped or where smaller map units are gradually extended

and joined together. Control of the second class is commonly carried along simultaneously with the topographic survey.

The topographic maps of areas in Alaska published by the United States Geological Survey have been primarily intended to supply geologic and other useful information to the American public. The facts that they were indispensable as a base for assembling and clearly presenting that information and that they have high intrinsic value solely as topographic maps require no emphasis, yet it was because of the demand for geologic information that funds became available for the topographic surveys. It will therefore be understood that they were incidental to work of a broader scope. This dependence is neither peculiar to surveys in Alaska nor is it an unusual condition in topographic surveying. Contoured maps are expensive to make. The impetus for carrying them through is almost invariably gained from some convincing need which entails the use of a base map.

It should be kept in mind that systematic surveys in a frontier country will be expensive, that so far as possible immediate demands for useful and reliable data must be met, and that the work should be done with all possible celerity. So, however desirable it might have been to commence a system of triangulation of the first order at the beginning of systematic surveys and to continue it to a measurable extent each year, this could not have been done with the small funds available without crippling the work for which the survey was primarily undertaken. Furthermore, in order that the greatest amount of information should be quickly gathered and that areas of special economic importance should first be mapped it was necessary to carry on detached surveys in widely separated regions, and it has not been possible to determine those regions long enough in advance to establish zones for a triangulation system that would supply usable results within a reasonable time.

From the foregoing remarks it is evident why the less precise type of control has been employed. The simplest methods were used in obtaining this control, and the time spent in the work was only as much as was thought necessary to procure sufficient data. The results obtained have on the whole been entirely satisfactory so long as the surveys, when joined together, have not embraced very extensive areas. As was expected, in recent years, where in some areas greater distances have been spanned, inherent discrepancies have developed, owing to the lack of more refined instrumental triangulation and geodetic adjustment, and these discrepancies had to be adjusted by arbitrary means.

As future surveys will join together still greater stretches of detached and semidetached areas, the need for better control will press apace. During the last several years, however, excellent systems of geodetic control have been supplied along much of the southern coast of Alaska

by the United States Coast and Geodetic Survey, along the international boundary by the International Boundary Commission, and in certain regions by the General Land Office.

Extensions from these systems can now be made, with much greater facility than formerly, to cover regions where precise control will soon be urgently needed. With the exception of certain surveys that could be readily controlled by direct connection with one or the other of the two systems mentioned above, topographic surveys in Alaska have been accomplished with the aid of control of the less precise character.

METHOD OF EXPANSION.

The procedure here described is followed in reconnaissance surveys. For larger-scale maps of smaller areas the main difference lies in the length of sights and the greater number of targets built ahead of observation work.

Ground is chosen to obtain a base as long as possible which shall have suitable points disposed to form a quadrilateral. From necessity the base is usually short, half a mile sufficing if natural conditions are favorable for expansion. The ground is staked and measured along the slope with a 100-foot steel tape. Levels are then carried over its length in order that the horizontal distances between stakes may be obtained. Targets are built at the ends of the base line and at every station in the initial quadrilateral. Beyond these stations sights are projected ahead at prominent and suitable mountain peaks. The aim is to obtain a checked distance between two elevated stations several miles apart before dispensing with targets placed ahead of observation. At the outset distances between stations must be selected to conform with the length of base in order to avoid angles which are too acute, and once this has been accomplished the triangulation net may be expanded and the distances between stations increased to 30 or 40 miles.

The ends of the base line and all stations of the initial quadrilateral are occupied with the transit, and the lengths of the sides of the triangles are computed, plane angles being used. Points representing the ends of the base line are plotted upon the plane-table sheet on the field scale to be used.

From these stations lines are also drawn upon the plane-table sheet to serve as checks on the computations and also to assist in establishing a rigid orientation. All other visible future stations are likewise sighted with the alidade. Two main difficulties confront the engineer in this work. First, he must keep in mind the several scattered peaks which he has selected as triangulation points and be able to identify them from different locations, and, second, he must exercise judgment as to the suitability of those points for future occupancy. The first difficulty is minified by the use of the plane table.

The second difficulty may be reduced by including other peaks near those of first choice for use as substitutes or alternatives, provided this is done cautiously, so as not to increase the number to the point of confusion.

In spite of the most careful work errors are liable to creep into the control scheme. In order to detect these errors and to determine their amount, an additional base should be laid out for every 50 or 100 miles surveyed.

LATITUDE.

Observations for latitude are made either by measuring the altitude of the sun at noon or the meridan altitude of a known star, and the transit serves for this work. All observations are made with the telescope direct and inverted. Declinations are taken from the Nautical Almanac. The formula for use in computing the latitude is

$$\varphi = 90° - (h - r - d)$$

in which h = altitude of sun's center or star, r = refraction, d = declination at time of observation.

The method gives only approximate results, yet by repeating the observations results can be obtained which are correct within 1,000 or 2,000 feet. If a series of observations is made throughout the field work a mean can be obtained, which should be used for the map. The results are not reliable enough to check the horizontal control scheme.

AZIMUTH.

Observations for azimuth are also made with the transit upon either the sun or a circumpolar star. Observations upon some star, as Polaris, at elongation give the most reliable results, but because of the long hours of daylight in high latitudes during the summer the stars are not often available. For stellar observations at elongation the formula is

$$\sin A = \sec \varphi \cos \delta$$

in which A = angle between star and true north, φ = latitude of place, δ = declination of star; and for convenience it is necessary to determine the local mean time of elongation.

For solar observations it is necessary to know the approximate time. A consistent routine should be followed in morning and afternoon observations in order to eliminate doubt as to which limbs of the sun are being observed. Observations are made primarily to obtain the altitude of the sun for use in the formula

$$\tan \tfrac{1}{2}A = \frac{\sin (S - H) \sin (S - \varphi)}{\cos S \cos (S - P)}$$

in which S = half the sum of P, φ, and H, H = altitude of sun corrected for refraction, φ = latitude, P = sun's polar distance, A = azimuth reckoned from the north.

If solar observations alone are used for orientation they should be made at points whose distances from one another are represented on the map by intervals not greater than 10 or 12 inches.

In determining azimuth the engineer should take care to have the distance between the station and the mark great enough to eliminate errors that might arise from eccentricity of the instrument and should carefully connect the readings with the map. The station selected for an observation of azimuth should either be sighted from another station that has been accurately located or its position should be exactly fixed in the triangulation scheme, and by either method due regard should be given to orientation.

LONGITUDE.

The lunar method for determining longitude is the only one available to the surveyor equipped with the means employed in surveys of the type under consideration, and this method gives results so incommensurate with the time and labor necessary for the observations that it is not commonly used. Therefore observations for longitude are generally made only in regions that have telegraphic communication with some established position. When a position is once established in a region it usually serves for all surveys which can be tied to it.

The Geological Survey has made no telegraphic longitude determinations in Alaska but has utilized several longitude stations determined by the United States Coast and Geodetic Survey, the General Land Office, and the International Boundary Commission.

VERTICAL CONTROL.

METHOD.

In reconnaissance surveys vertical control as well as horizontal control presents difficulties. Where a topographic map of a region remote from any previous hypsometric communication with the sea is to be made the factors for determining the method of vertical control are the expense, time, and degree of accuracy desired. If a possible error as great as 10 per cent is allowable the aneroid barometer will furnish the simplest and easiest beginning. For most purposes a topographic map whose contours all indicate the country to be 10 per cent higher or lower than it really is would be as serviceable as one built upon a correct initial elevation. With present-day facilities in map printing by photolithography the later adjustment to the correct datum would not be a serious difficulty. At some

expense of time and funds a set of mercurial barometers may reduce the probable error in datum to 5 per cent. From methods whose cost is nominal and whose probable error is great the step is made abruptly into methods that entail great expense. Two of these methods are available, namely, vertical angulation and spirit leveling; the latter is the most precise method in general use. Unfortunately it is impracticable for initial surveys, such as those made in Alaska, because of the absence of highways or other possible routes for extension. Vertical angulation then remains as the only practicable and dependable method for these surveys.

In the earlier surveys in Alaska, where no connection with sea-level or some previously determined points could be readily obtained, the datum for elevations was determined by mercurial barometers. Some of these determinations served for connected surveys that were carried through several seasons and embraced several thousand square miles of territory. The maps resulting from these surveys were therefore consistent with the initial degree of accuracy, for vertical angulation, which was used to extend the vertical control, introduced very small cumulative errors.

Through the work of the United States Coast and Geodetic Survey, the International Boundary Commission, the Alaskan Engineering Commission, and the General Land Office the precise altitude of a number of stations in Alaska is now known, and many of the later maps of areas in Alaska have been based on these altitudes.

DEGREE OF ACCURACY ATTAINED.

TABLE 5.—*Accuracy of elevations determined with the telescopic alidade.*

Distance between points (miles).	Average number of readings.	Mean variation between computed elevation differences (feet).
3- 5	4	1½
5-10	4	3½
10-15	5	6
15-30	7	21

The average cumulative error in vertical angulation in surveys in Alaska has been estimated at not more than 25 feet in 100 miles. In a recent survey the error in 250 miles is but 60 feet, and as this error was distributed over about 100 stations the average error per station is less than 1 foot.

All the main sources of error in vertical angulation can be eliminated or fairly well determined except those caused by refraction of light. The errors chargeable to other causes may be reduced to almost negligible quantities by careful and consistent manipulation

of the instruments. As errors due to refraction may be greatly reduced by employing averages of many angles, readings should be made upon all visible stations and control points from the greatest possible number of stations.

STATION WORK.

USE OF PLANE TABLE AND TELESCOPIC ALIDADE.

When the distance between two points and the true or assumed elevation of one or both of them have been determined the work of the plane table is mainly that of expanding the horizontal and vertical control in order that the photographs may accurately and readily supply all the information they contain. A detailed explanation of the station work with the plane table need not be given here. There are many points, however, in the use of the alidade which in order to obtain the best results require constant watchfulness, and, moreover, these points the inexperienced topographer is liable to neglect by failure to realize their importance. Every possible check upon the work should be obtained as it progresses. Next to the task of keeping track of the almost numberless lines on the sheet the hardest is to locate the stations with uniform accuracy. The frosted celluloid is here of very great value, for by its use the adjustment of the position of a station may be postponed until the weather is more favorable or until additional control has been procured. The number of lines which must be drawn upon the plane-table sheet from stations is very much reduced by the use of the photographic method. It is a simple matter to retain in mind or to describe two or three dozen objects sighted. It is not necessary, therefore, to locate the station on the map before the lines are drawn, but they may be kept on the transparent celluloid until the topographer is ready to transfer them to the map. In this manner stations which at the time they are occupied can not be definitely located on the map are merely held for additional observations. Plane-table work should be done with all possible skill, for a failure to use every means of refinement available reduces by so much the chance of keeping the errors in the negligible class.

SELECTION OF STATIONS.

The most difficult feature of the field work lies in the selection of stations. The necessary number of stations and no more should be chosen for the camera, in order that progress in the field work may be as rapid as possible. If the dependable reach of the photographs is known the task is to find the favorably situated peaks from which the greatest proportion of the surrounding topographic features can be

seen. Experience has shown that if all the stations could be located on commanding peaks all the data necessary in the photographs could be obtained by selecting peaks from 8 to 10 miles apart. Unfortunately the most prominent peaks are not so regularly placed, and many of them can not be ascended without special equipment for mountain climbing and an unwarrantable expenditure of time. As the topographer is thus forced to take less favorable positions, he must keep track of those parts of the country which the camera has not photographed and must obtain the additional views at other stations. This feature will not only require continual watchfulness but there will be a corresponding reduction in the rate of progress on the map owing to the reduced efficiency in the stations. Ordinarily three inferior stations will be required to supply the data that can be obtained at one first-class summit. Where it is reasonable to assume that a more favorable peak can be climbed, the desirability of occupying it should be considered in the light of the time and energy necessary to occupy the three less favorable stations.

In order to estimate the influence which the relative elevation and isolation of the station have upon its value for the work a number of photographs taken from different elevations have been examined to determine the amount of information they supplied for constructing contours. The specimens were selected from reconnaissance surveys, and estimates were made for percentages of a unit of area whose radius was 5 miles. The results are shown in the following table:

TABLE 6.—*Relative value of stations.*

Station No.	Relative elevation of station.	Average distance of higher portions of area (miles).	Percentage of area higher than station.	Percentage of area shown in photographs.	Percentage of crests visible.
1	Highest point		0	50	95
2	.....do		0	60	100
3	.....do		0	75	98
4	At mean of relief	4	40	60	70
5	.....do	3	20	40	30
6	At three-fourths of relief	2	10	42	50

The result of the examination is decidedly in favor of the highest peaks and most isolated points as against a greater number of points of smaller visual range. Under ideal conditions where stations a few hundred feet higher than any other points in the circle could be chosen the rate of daily progress would be about 200 square miles. The difference between this figure and the progress that has actually been made suggests that the selection of stations deserves all the attention the topographer can give to it. Difficulties met in traveling have a marked influence upon the rate of progress of topographic surveys, however, so that the disparity between possible and actual

results can not be entirely eliminated by selection of more favorable stations.

In the examination whose results are given in Table 6, station 1 was situated at the edge of an intricate mountain mass, so that it embraced a wide valley on one side and many ridges and spurs on the other. It was isolated with respect to nearly one-half the area. The area shown in the photographs is small, but as most of the crests are visible the station should be rated as well selected. Station 2 was surrounded by less complex topographic forms, so that though the ratios indicate more efficient photographs than those obtained at station 1, the actual number of points supplied by them was considerably less. Station 3 was well isolated and surrounded by country of simple topography. The high value of the photographs taken at station 4 is due to the isolation of the station. The photographs taken from stations 5 and 6 have only between one-third and one-half the value of those taken at more favorable locations.

USE OF CAMERA.

MANIPULATION.

The manipulation of the camera at the stations is simple. At most stations it is necessary to shift the camera to one or two near-by positions in order best to photograph the country. When the camera is moved to near-by points the directions and distances from the station to the substations are noted. As a rough guide to the photographs the general direction of the view must be known. Some known point mentioned as "near center," or "20° from left edge" adequately indicates the relation of the negative to the map. The camera is equipped with guide lines on top which include a scope of 120°. A mental note is made of distant objects in range with each of these lines for the camera's position during the first exposure. For the second exposure the camera is turned to embrace the field where the first left off. For the third exposure, a test sight should also be made as a check to see whether the field of the third view joins that of the first. A compass may be used to turn off the angles between exposures, but it should be checked by the open-sight process.

The wind guys should always be used when the wind is 5 or 6 miles an hour or more. Mountain tops are at all times subject to puffs of wind. The shortest time of revolution of the lens is several seconds and as the camera must be kept as stable as possible throughout the exposure, all precautions to that end should be taken.

Films should be put in and taken from the camera at the stations, for if a roll is left unsealed long it will absorb enough moisture to injure the emulsion. This precaution is especially necessary if the exposed films are to be held several weeks for development or if

they are to be resealed in the water-tight cans. The exposed films should be repacked in the cans to protect them, and this can not be done with safety unless the films are kept dry.

DETERMINATIONS OF DURATION OF EXPOSURE.

The most interesting part of the field work is to be found in the search for the proper duration of exposure. Different conditions of the weather, which cause unequal lighting, and a great range of subject in both kind and distance present exceedingly difficult obstacles to the attainment of uniform efficiency in negatives. Smoke is a serious impediment to topographic surveying. Its presence in quantities may check phototopographic work entirely, and it always curtails the effective range of the camera. Its effect is perhaps even more serious on phototopographic work than on the ordinary telescopic plane-table work. In general, when the atmosphere is smoky the camera can not be relied upon for distances greater than one-third the range of the unaided eye. In other words, if the atmosphere is smoky and topographic forms stand out unmistakably to the natural vision at a distance of 10 miles from the station the camera will not likely reach more than 3 or 4 miles. In many regions a more or less smoky atmosphere is common, and the less frequent clearer days should be utilized to obtain a fair number of longer-range negatives. With present-day facilities it is very difficult to give to a single negative the proper exposure to obtain clear images both of details along near and dark slopes and of peaks 15 to 30 miles away. On the brilliant days duplicates should invariably be taken, with a light equivalent for the distant country about one-fourth that for the nearer. Films are so easily transported and the panoramic camera requires so little time to operate that whenever doubt is felt as to the result duplication should be the rule. One of the most advantageous features of the panoramic camera is that it permits an elimination of uncertainty in exposure because it can be operated rapidly and photographs covering the whole range of aperture may be taken in a very few minutes.

Attention should be directed to the great difference in the amount of light reflected from bare areas and from heavily wooded country. Dense timber absorbs much more light, so that the exposure for timbered areas should be about eight times as long as that for the higher levels. In passing from bare mountains to timbered valleys the photographer is likely to err in not making sufficient allowance for the increased absorption. Furthermore, the atmosphere in valleys is less clear and more disturbed than that at the tops of the mountains. This condition gives rise to much interference of the light rays entering the lens; details are lost by the increased haze, and inferior negatives result. In general, the higher the position

of the camera, the better is the atmosphere for photography. Exposures should not be made from the floor of a valley or plain when these positions can be avoided. Even a slight knoll will raise the lens above much of the unfavorable atmosphere, and the higher the knoll the better will be the results. This rule holds true upward to the highest peaks. The photographer should keep in mind these general rules in order that he may be able to judge fairly well by the eye what the range of his camera will be when he occupies stations in different types of country and under different atmospheric conditions.

In determining the most favorable weather for photographic surveying it must be borne in mind that the lens is to be directed toward every point of the compass, so that a condition which might be best for a view in one direction will most likely be poorly suitable for the landscape in the opposite direction. A typical condition is that where a slanting sun casts shadows that accentuate slopes and gulches. The surveyor can neither choose the time for exposure nor move his camera to catch the best lighting. Except within very narrow limits, wherever the sunshade permits, he must take photographs at all hours of the day, regardless of the position of the sun. That condition which is nearest uniform over the country to be photographed is in general the most favorable.

The following schedule for classifying conditions of lighting has been found very practical:

	Value.
Fair; no clouds or a few detached clouds; sun high	1
Fair; in the direction of the sun when the sun is low	2
Many detached clouds (requires two exposures)	1–4
Cloudy; landscape completely shadowed by thin clouds	2
Cloudy; landscape completely shadowed by thick clouds	4
Stormy; rain and mist over portions of landscape	4–8

The first of these conditions is, until middle afternoon, the most favorable for landscape photography. By late afternoon, because of the greater radiation from the earth, the haze becomes too great for the best work at long range, and very late in the afternoon the sun will destroy images in its direction. Frequently in the higher latitudes an excellent condition for photography exists immediately after sundown, when the shadows have disappeared and the light has become more uniformly diffused. The presunrise glow offers the same advantages. The exposures at these times should be about the same as for the lighting just before sunset or after sunrise.

The next most favorable condition is that when a high stratum of clouds completely overcasts the country. If the atmosphere is then free of smoke the camera's range is practically as great as during fair weather. If the clouds are gray there may be some difficulty in distinguishing very distant snow-capped peaks.

Detached clouds cause local difficulties by casting shadows that appear like hillocks on the photographs. These shadows can usually be detected by comparison with companion views obtained on other days. The difficulty may be further lessened by taking duplicate exposures after sufficient time has elapsed to allow the clouds to shift their position. If detached clouds are numerous, exposures should be made both for the shadows and for the sunlit areas. Exposures made under this condition give negatives of irregular range, yet little difficulty is experienced in their use for a range of 5 or 6 miles or less. Beyond that distance some portions will be clear, but others will be too uncertain to furnish accurate information.

During stormy weather the camera work is hampered to a serious degree. Rain and mist even in very slight quantities form impenetrable screens to photography. The only recourse is to duplicate the exposures by watching for chances between showers. Allowance should be made for a greatly reduced range.

The following table showing records of exposures is inserted as a guide in the use of calculators or meters:

TABLE 7.—*Records of exposures in latitude 62° N.*

Date.	Elevation (feet).	Hour.	Weather.	Subject.	Direction.	Stop.	Time (seconds).	Remarks.
June 20	6,000	11 a. m.	Fair	Dark mountains with much snow.	Southwest.	F 8	1/5	Screen with factor 32.
20	6,000	11 a. m.	do	do	North	F 11	1/5	Do.
July 10	5,700	6 p. m.	do	do	East	F 6.3	1/6	Do.
Aug. 15	5,700	3 p. m.	do	Dark mountains.	North	F 6.3	1/5	Do.
18	6,200	2 p. m.	do	Dark mountains with much snow.	South	F 8	1/5	Do.
Sept. 13	5,400	4 p. m.	do	Dark mountains.	East	F 6.3	1/2	Do.
15	1,000	10 a. m.	Densely cloudy.	Dark valley slopes		F 6.3	1	Do.
22	At sea level.	9 a. m.	Fair	Partly timbered dark slopes.	Northwest	F 6.3	1/7	Do.
Oct. 5	do	2 p. m.	Densely cloudy.	Mountain tops powdered with snow.	South	F 6.3	1/2	Do.
5	do	2 p. m.	do	Dark timbered slopes.	do	F 6.3	2	Do.
1	3,000	5 p. m.	do	Timbered slopes and valley.	do	F 6.3	1	No screen.
1	3,000	5 p. m.	do	Snow - covered mountain tops.	do	F 8	1/5	Do.

AUXILIARY CAMERAS.

Surveys with the panoramic camera are greatly facilitated by the employment of one or two auxiliary cameras, especially if a route must be rapidly traversed and as great a scope of country mapped as possible, which is a common condition in reconnaissance surveys. Panoramic photographs have a greater value here than those of all other types in that they show readily and accurately the position from which they are taken. As a check telescopic readings are made upon as many of these subsidiary camera stations as can be obtained. The practice as pursued in Alaska has been to employ two cameras

in the topographic party. The photographer then makes daily trips on one side of the course traveled and the engineer and assistant work on the other side. The two cameras should commonly occupy stations from 5 to 10 miles apart in order to cover the maximum area, though they remain near enough together to close up the stretches between. The width of country which can thus be embraced in the map is nearly double that which the engineer alone could cover. A third camera would considerably increase the daily area, though not quite in the same ratio, except in regions of unusually favorable topography.

The photographer is equipped with a camera and all the necessary detached parts, a tripod, a 12-inch plane-table board, a 10-inch open-sight alidade, a compass, an aneroid barometer, and a notebook. He travels alone and carries a pack which weighs about 30 pounds. Besides taking the usual number of photographs at his stations he takes half a dozen or more sights at other stations and prominent peaks, on frosted celluloid with the open-sight alidade on the small board. The barometric elevation is also recorded, and when he doubts that the photographs will show the shape of the mountain occupied he sketches a few contours close about it. Lastly, he should indicate briefly those portions of the area within a radius of 10 miles which the photographs cover. The sights taken at his stations, though not essential in establishing the positions of the stations on the map, have immediate value in indicating where the topographer should look for those stations and in the selection of future stations. The sketches of the country photographed from the stations help the topographer in choosing stations for succeeding days. The degree of success which the photographer attains with his work depends on his aptitude as a mountaineer, topographic sense, hardiness, and ability to retain a correct mental picture of the country he sees. Experience in topographic surveying tends to develop all these qualities, and therefore such training, though not essential, is helpful to the photographer. Likewise, familiarity with cameras aids to a considerable degree, yet the manipulation of the panoramic camera can be readily acquired by all who have a proper appreciation of the accuracy demanded in surveying instruments.

By alternating from side to side the topographer can keep track of the photographer's stations and the scope of his photographs and thus determine the progress of the work. Consultations over the progress sketch will then clear up the doubtful spaces.

The following records of a photographer's work on four consecutive days indicate in another way the nature of his task. The records are typical.

July 25.—On this day camp was moved 8 miles. Left morning camp at 6.30 a. m.; arrived at evening camp at 5.45 p. m.; distance traveled 14 miles. Altitude climbed during the day, 3,500 feet. Number of stations occupied, 2. Time spent on stations, 3 hours Number of photographs taken, 12. Sights taken to 15 points; slight sketches.

July 26.—Time between camps, 13 hours Distance traveled, 11 miles. Altitude climbed, 2,700 feet. One station occupied. Time of occupation, 5 hours (delayed for weather to improve). Four photographs taken. Thirteen sights and sketch. Camp moved 6 miles.

July 27.—Camp not moved. Left camp at 4 o'clock a. m. and returned after 6 p. m. Distance traveled, 10 miles. Climbed over 6,000 feet and occupied 4 stations. Sixteen exposures but no sights Time on stations, 3 hours and 40 minutes.

July 28.—Camp moved 9 miles. Time between camps, 10 hours. Distance traveled, 15 miles. Altitude climbed, 4,000 feet One station and 2 substations occupied. Eight exposures. Time on stations, 2½ hours (delayed by wind). Eight sights and sketch.

DEVELOPMENT OF FILMS IN THE FIELD.

As soon as possible after field operations have been started a few films should be developed to ascertain the results that are being obtained in the negatives. A fair-sized tent should be available for the work of development, and in high latitudes this tent should be heated, in order that the development may be carried on satisfactorily during stormy weather, when regular work at stations is interrupted. The writer has used the camp's cook tent, size 10 by 12 feet, which was satisfactory for developing a small number of films at a time, but in order to develop a large number of films a tent should be provided for that purpose. Whether the extra tent is to be taken should depend on the means of transportation and the length of time which would elapse before the exposed films could be got to headquarters for development. Fresh films can be kept several months after exposure without noticeable deterioration, provided they have been kept dry.

The strength of the developing solution and its temperature should be accurately known when the film is developed in order that the development may be properly timed. The temperature of the solution should preferably be near 65° F. and never above 70°. After development the film is rinsed in cold water eight or ten times before removing it from the tank. All water used for solutions, rinsing, and bathing should be clear and free from matter in suspension.

Until the film has been passed through the fixing bath it will be affected by light. However, the effect of subdued daylight upon the film during the change from the developing tank to the fixing bath is so slight, when the operation is done quickly, that it may be safely accomplished outside a dark room. Negatives which have thus been changed in a white tent on cloudy days have not been noticeably affected. While in the fixing bath the films should be shaded or covered until the fixing solution has begun to act. They may then be drawn through the bath by raising and lowering while being held at the ends. This process will insure uniform action of the fixer.

It is highly important for the films to be thoroughly washed after fixing. This can be readily and effectively done by stretching them horizontally in a pool of a stream where there is little current. In

putting the films in the pool and removing them care should be taken not to stir up the sediment in the bottom of the pool or in the stream above it. The films should remain in the water half an hour. If they are washed in basins the water should be changed four or five times and the films allowed to remain immersed for an hour or more.

The films are hung up to dry by clips and anchored to the floor from the lower end. The temperature of the tent should not be allowed to go above 80° F. while the films are drying. Noncurling films will twist and curl while they are drying but will flatten out when completely dry.

When dry the developed films are labeled according to roll and exposure number and then cut. They should be packed flat. In order that intelligent judgment may be passed upon the resulting negatives, some skill must be attained in appraising their quality. The negatives are examined for density, definition, and clearness in details. If possible, a sample negative embracing a broad landscape should be kept for comparison. This should be one from which the clearest possible prints have been obtained. Notes are made for guidance in making future exposures.

TRAVERSES.

Roads, railroads, and trails have not been built over any great extent of Alaska, and hence in the reconnaissance surveys the time necessary to make traverses of these features is very slight. The few traverses necessary can be executed without instruments in addition to the regular equipment. In the more detailed surveys, however, roads, trails, and many of the stream courses require traverses of some character in order that they may be placed upon the map with accuracy. The camera can seldom photograph more than portions here and there of such features, although localities where trails zigzag up a slope afford unmistakable subjects for its work. The camera is relied upon to locate and furnish the elevations of a sufficient number of points to control the traverses.

The method of executing the traverses depends on the character of the feature to be traversed, the relief, and the degree of accuracy desired. Under favorable conditions, such as are found in traversing a railroad or a good road, the best results can be obtained by stadia or micrometer, the elevations being carried along by vertical angles. In a rough country over trails or poor roads and along small streams another method is usually employed, which is more practicable, permits greater speed, and, if properly controlled, gives results of a refinement commensurate with the ruggedness of the country. Distances are obtained by a line (cord or linen tape) and the aneroid supplies the elevations. The work of the magnetic needle and tape

in these traverses is commonly much more satisfactory than that of the aneroid. This instrument is liable to eccentric errors, which necessitate a continuous watchfulness in its use. The smaller tripod and board here supplement the larger instruments. For brush work a board about 7 inches square, or no larger than is necessary to contain the work of one day, is advantageous.

The extent of traverses is shown by the red lines on the Port Valdez map (Pl. I, in pocket).

USE OF PANORAMIC CAMERAS ABOARD SHIP.

The field season of 1916 afforded an opportunity to use the panoramic cameras aboard a launch in the sheltered fiords of Prince William Sound, Alaska. The mountains there rise rather abruptly from the water's edge, and their tops reach elevations ranging from 2,000 to 10,000 feet. The conditions were, therefore, unusually favorable for this work. A 40-foot gasoline launch was used for the cruises and two cameras were mounted on a stand with gimbal rings (Pl. V, *A*, p. 32). The stand was made of wood and stood about 3 feet high. The gimbal rings were made of cast brass and the bearings were wedge-shaped. A brass tube 2 feet long was suspended from the center of the inner ring to support a stabilizing weight. In order to reduce the sensitiveness of the gimbals it was found desirable to attach four stiff coil springs to the lower end of the tube and stretch them to the legs of the stand. Three short brass posts formed a support for a circular top plate which could be rotated in any desired direction. The circular plate was made of 1-inch pine boards, and a slotted brass ring plate was screwed to its under side to receive the heads of the posts. At the rim of the circular plate and spaced 120° apart were fastened two upright wooden posts having brass plates on top similar to tripod heads. To these plates were screwed triangular adapters, and the leveling screws of the cameras rested in the adapters as when mounted on tripods. A bag of shot about equal to the weight of one camera was placed on top of the circular plate to counterbalance the weight of the cameras. The cameras were adjusted in position so that when exposures were made a few degrees of the horizon were included in both negatives. The cameras were loaded and made ready for exposure before mounting. After they were mounted in the adjusted positions the engine was shut off, and they were leveled as carefully as the oscillations of the boat permitted. Exposures were then made at the moment when the movement of the boat seemed least. At the time of exposure all men aboard remained still and in selected positions, and the boat was kept on a given course. The maximum speed of the boat was 6 knots, and at the time of exposure this was usually reduced to about 2 or 3 knots.

The scale of 1:90,000 was used in the field for plotting the control stations and adjusting the traverses of the survey, but in the office compilation the map was drawn on the scale of 1:180,000, with 200-foot contours. The survey covered about 2,000 square miles of territory and included 562 miles of stadia, micrometer, and tape traverses. The launch was run about 220 miles, and 220 pairs of photographs were taken during the cruises. The time spent in running was 58 hours. Furthermore, in order to expand the triangulation system from the points supplied by the United States Coast and Geodetic Survey, 42 plane-table stations and, in addition, 62 camera stations on land were occupied. These stations supplied a sufficient number of secondary points to establish the positions of the boat at the moments of exposure. These positions were determined by the use of transparent celluloid sheets, as described under the heading "Station work" (p. 41). The negatives resulting from the exposures aboard the launch were on the whole very satisfactory, but could have been improved by the use of a larger boat, which would not have been so greatly affected by swells.

The photographs reproduced in Plates VI and VII were taken from the moving launch and are part of a series that covers a certain landscape. As the horizon line (in these views the shore line) is slightly curved, measurements for altitude were made from the shore line immediately under the points sought instead of from a horizon indicated at the edges of the photographs. In general these measurements are reliable when the definition of the image is good.

There are three sources of error incidental to the use of the panoramic cameras aboard ship, which are thus classified:

(1) Errors due to the forward movement of the boat at the time of exposure. The time required for exposures is about 5 seconds. The speed of the boat should therefore be reduced according to the scale employed for the map, so that the amount of displacement of the boat during exposure will not affect the graphic plotting of positions. If the scale is a mile to the inch, 25 feet may be assumed as the limit for this error. For this scale, therefore, the speed of the boat should not be allowed to go much beyond 3 miles an hour.

(2) Errors due to the ship swinging off course. To obtain accuracy in graphic plotting by the use of photographs on the scale mentioned it will be necessary to keep the course of the vessel within 5′ of arc in order to use points that are as far as 10 miles from the camera. For less distances the limit may be increased in proportion. Except when the beam wind is blowing, little difficulty will be experienced in fulfilling this requirement.

(3) Errors due to the oscillations of the boat. These errors are the most serious, and their amount will depend on the altitudes of

points and their distances from the cameras. As shown in figure 5, where a = half the angle of oscillation, x = the amount of displacement of the image of the point due to oscillation, v = the vertical distance of the point above the horizon, f = the focal length of the photograph, d = the map distance from the camera to the point, and e = the allowable error at the distance d, we shall have

$$x = v \tan a$$

and from the similar triangles the proportion

$$f : v \tan a = d : e$$

whence

$$\tan a = \frac{fe}{vd} \quad \text{.....................} (1)$$

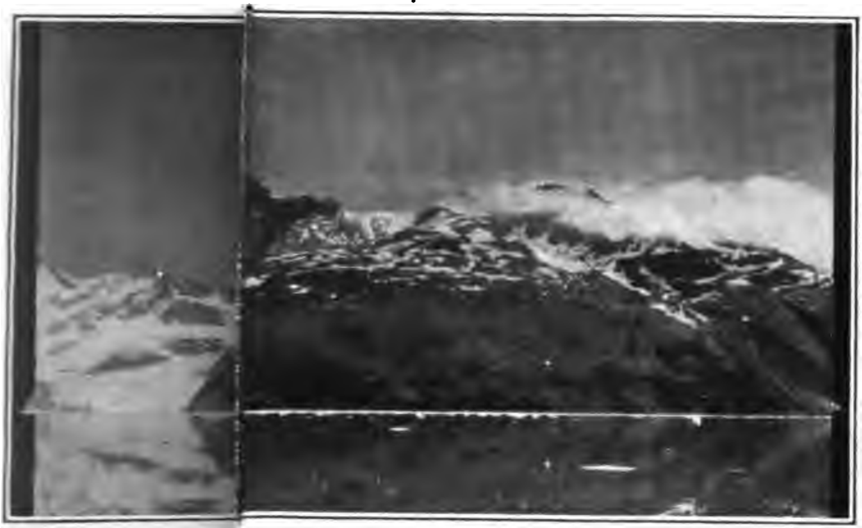
As an extreme example, a point 10,000 feet high, which appears in one of the views shown in Plate VII, will serve to determine the angular value allowable for oscillation of the boat when the scale is a mile to the inch. The image of this point, which is the highest in the area photographed from the boat, is 1.42 inches above the horizon. The photographs used have an average focal length of 5.3 inches. Therefore, if v is 1.42 inches d will be approximately 7.25 inches (the point is 7.25 miles from the camera). The limit of error that would be allowable in the radial line from the camera to the point is 0.005 inch. Applying these values to equation (1), we have

$$\tan a = \frac{5.3 \times 0.005}{1.42 \times 7.25} \text{ and } a = 9' \text{ (approximately).}$$

Therefore the maximum angle which is allowable for oscillation of the boat, when the scale is to be a mile to the inch, may be taken as approximately 18′ of arc. The level bubbles used on the cameras should be graduated far enough each side of the center to indicate when this limit is reached.

The photographs obtained from a boat in the manner described have certain advantages and limitations. By the use of the cameras aboard a boat it is possible to obtain photographs from positions which otherwise could not be utilized. Along much of a bold coast line, such as is typical in certain parts of Alaska, these photographs will be adequate, with the necessary control and traverses, to complete the topographic survey of a considerable strip of land adjacent to the shore. Often, however, in order to obtain all the information necessary to complete the survey, it will be necessary to supplement the marine photographs with others taken from summits. However, the number of stations that must be made on land will be few, and they can be definitely determined at the time of the cruises in order

TO SHORE.



TO SHORE.

to be most useful. By utilizing to the fullest possible extent the small number of fair days in those regions of the coast where misty and rainy weather prevails the method promises to be particularly valuable. In the field work of 1916 about 40 per cent of the weather was unsuitable for either station work or photography, but the delay on account of weather was negligible, for the station and photographic work was kept well ahead of the traverses, and these were run in almost all kinds of weather. It is probable that in similar surveys the method will allow the field work to progress unhampered during seasons when unfavorable weather runs as high as 60 per cent.

The range of the photographs taken aboard ship is not so great as that of photographs taken inland, for the reason that the oscillation of the boat will prevent sharp definition in images of very distant points. However, if the defects due to the ship's motion, as stated above, are reduced as suggested, there should be little difficulty in using points 12 to 15 miles away.

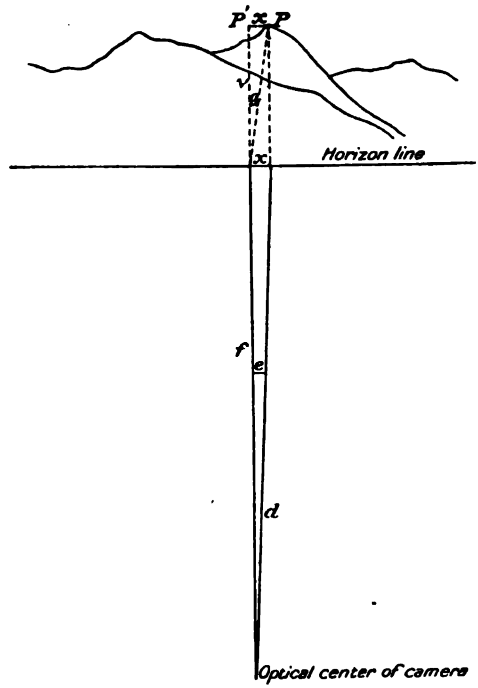


FIGURE 5.—Limit of oscillation of boat carrying panoramic cameras during exposure of the films.

OFFICE INSTRUMENTS.

PANORAMIC PHOTO-ALIDADE.

If the straight line AB in figure 6 represents the rectified arc RR′ of a circle which subtends the angle X, then any part of AB, as AP, will, if measured along the arc, subtend an angle B, which may be thus expressed:

$$B = \frac{AP}{AB} X$$

If, therefore, the point P in traveling from A to B can be made to rotate a radial arm about O through the angle x, the arm will indicate the direction from O to any point on AB at which P may stand. Now, AB may be considered as representing the horizon line of a photograph obtained with a panoramic camera and ROR′ a

horizontal section of the camera containing the optical axis. Then, if the photographs were all of the length AB, a simple mechanism which maintained the relation indicated would supply the direction of any point of a photograph with reference to some other point of the photograph. As a matter of fact, although photographic paper prints made from the same negative run closely to a common size, there is a slight variation. Furthermore, such a mechanism should be suitable in both damp and dry weather, not only for prints made from numerous negatives obtained in a single camera but for those of several cameras equipped with lenses of slightly different focal length.

To meet these conditions the device must be adjustable. If, therefore, in figure 6, the photograph has a length AB′ greater than

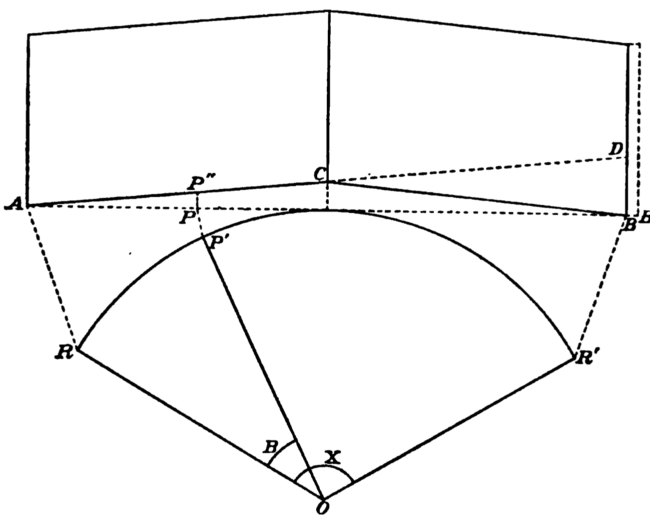
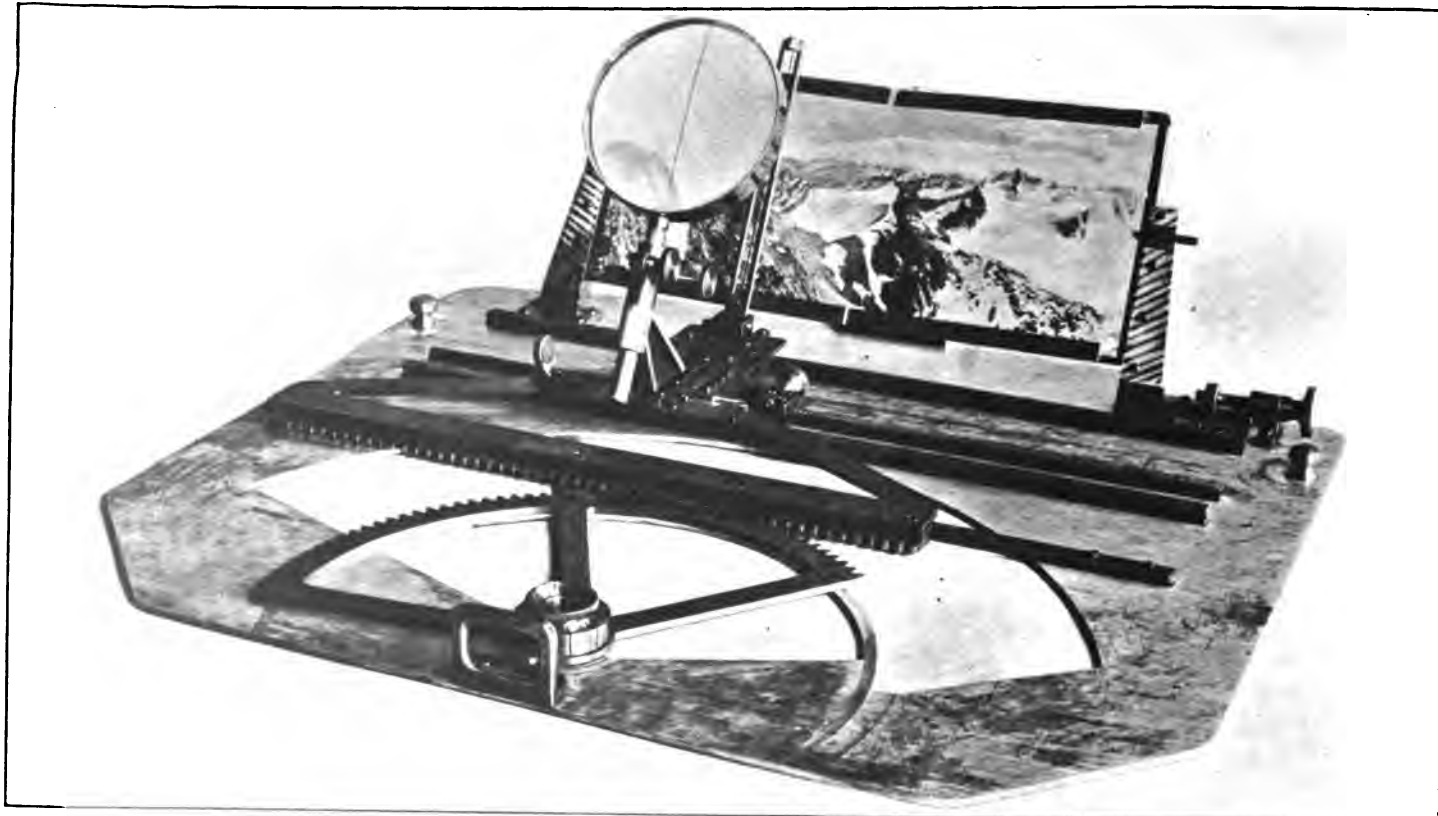


FIGURE 6.—Principles of the panoramic photo-alidade.

AB, the instrument may be "broken" at the middle, so that in hinging on the axis passing through that point the end B′ can be made to fall at B, and the triangle ACB thus formed will be an isosceles triangle. The effective length of the photograph will now equal the arc RR′, and if, as the point P moves along AB, perpendiculars to AB are drawn from P to intercept the broken line ACB, as PP″, the radial arm OP′ will indicate the direction of the point P″ from O. This relation may be shown as follows:

AC is prolonged to meet at D the perpendicular to AB erected at B. Then CD = CB and the two similar triangles AP″P and ADB give the relation

$$AP : AP'' = AB : AD \ (AD = AC + CB)$$



PANORAMIC PHOTO-ALIDADE.

Plate VIII shows the instrument that was devised on the principles explained above to obtain upon the map sheet directions of points contained in panoramic photographs. In order to impart the rotary motion to the radial arm, the circle to which the arm is fastened has teeth which engage with a movable straight-line rack. The rack is moved distances equal to the spaces between points on the photographs, and the arm attached to the gear wheel is rotated through the angles which those spaces represent. The photographs are contact prints, not enlargements, but they vary a little in length and width. Furthermore, the lenses differ slightly in equivalent focal length. In order to take care of this range in sizes of prints, the gear wheel is cut with a radius a fraction of an inch less than the focal length of the shortest prints, and the frame, which hinges at the middle, can be "broken" by means of the screw at the extreme right of the instrument, so as to cause the ends of the photograph to rest at a distance apart which will give the camera's fixed angular scope (approximately 126°). The line of sight is at right angles with the line of the rack and the horizon line, so the two last-mentioned lines are parallel. The gear wheel revolves around a point which represents both the optical center of the lens and the camera station. A centering device is arranged so that this point can be placed over the position of the station on the map. Furthermore, in order that the photograph may stand in a position convenient for sighting, the frame which holds it is inclined at an angle of 30° to the vertical.

ROTARY SCALE.

The instrument that has been constructed to expedite the measurement of distances of points above or below the horizon line on the photographs is shown in Plate IX. It consists of a movable traveler which carries a taut wire stretched at right angles to the direction of movement. At one end of the traveler is placed a rotary dial, which is geared to a rack attached to the traveler. Movements of the traveler are registered on the dial. The dial is graduated to hundredths of an inch and can be read approximately to five-hundredths of an inch. A base plate is provided in order that the frame which carries the mechanism may be clamped to it so as to hold the photograph in place. The dial is revolved until it registers zero; then the photograph is inserted and the wire placed along the horizon line. The clamp is thrown on and readings are noted. The factors obtained by use of this instrument are employed along with the corresponding map distances to obtain differences of elevation.

ELEVATION COMPUTER.

Figure 7 shows the device employed to determine differences in elevation between points on the map. The principle of this device is that the series of triangles formed in the camera are similar to the corresponding series existing in space at the station. In the camera the focal length of the lens is homologous to the horizontal distance from the station to the point, and the distance that the image of the point lies from the horizon line is homologous to the difference in elevation between the station and the point. Whence comes the formula

$$\text{Difference in elevation} = \frac{VD}{F}$$

in which V is the quantity obtained from the photograph, D the map distance, and F the focus for the photograph. The apparatus, therefore, has two horizontal scales, which are laid on a single line

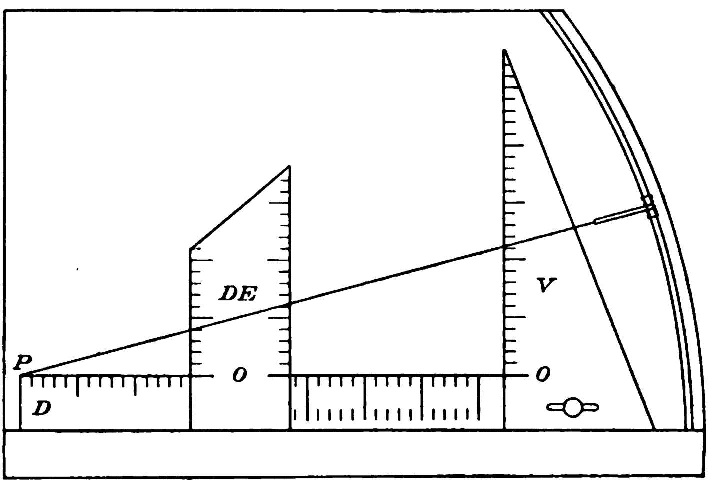
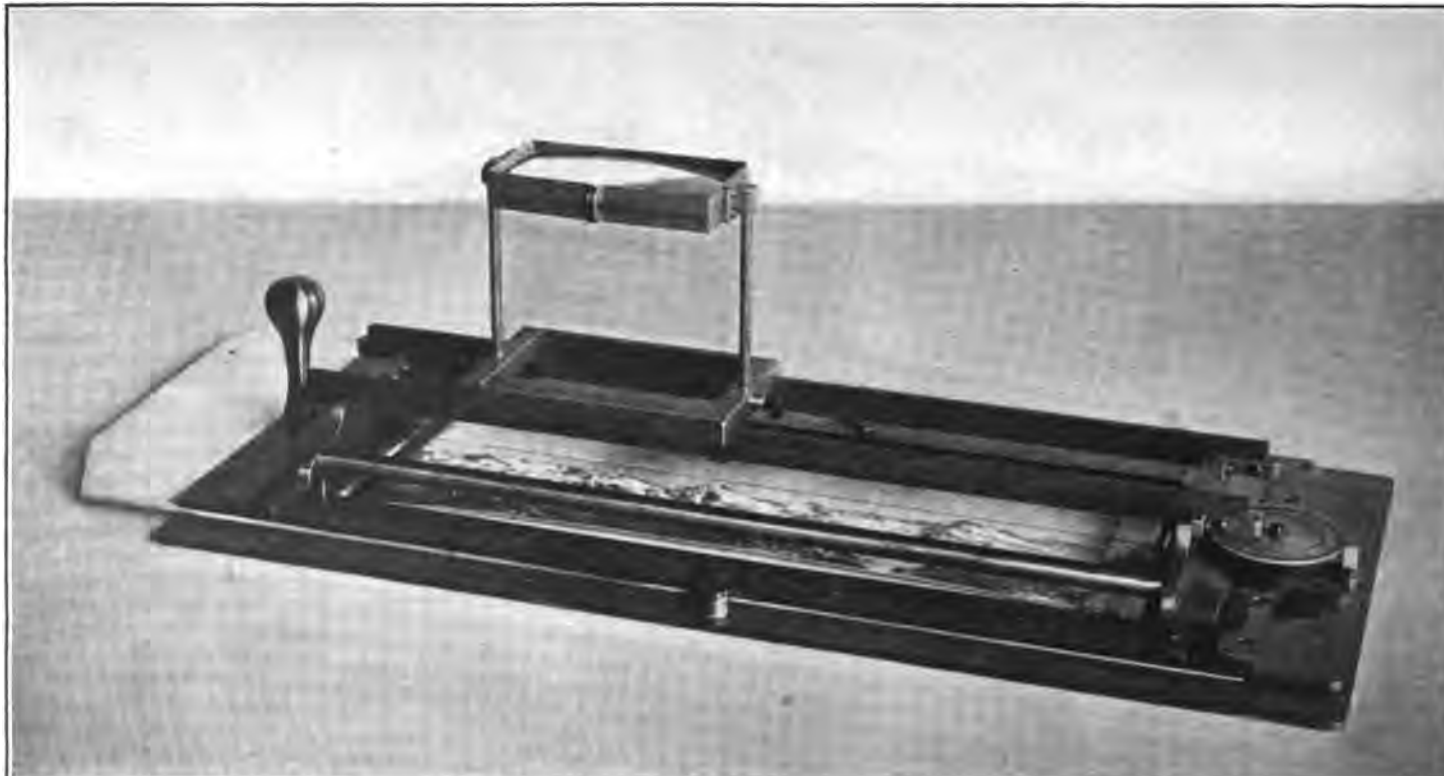


FIGURE 7.—Elevation computer.

in the plane of the horizon, and two vertical scales, which are laid at right angles to this line. The pivot point P represents the station and the optical center of the photograph. The vertical scale marked V represents the photograph, and the other vertical scale represents the point whose elevation is sought. The distance from the pivot point to the scale marked V is taken as equal to the focal length of the photograph, or some multiple of it, and the scale V is graduated to correspond with this relation. The scale D is assumed as a convenient quantity, and the scale DE is made to correspond with it. The vertical scales read zero at the horizon line. The thread is set at the quantity V on the scale V, the scale DE is brought to the point on the scale D which reads the distance as scaled from the map; and then the difference in elevation is read



ROTARY SCALE.

from the scale DE. If the focal distance and the scale V are doubled and the two remaining scales are 1:48,000, the differences in elevation can be read to 10 or 15 feet, and the proportions will require a board about 14 by 18 inches.

LOGARITHMIC PLOTTER.

A logarithmic plotter, which is to be constructed, has been designed in order to obtain an instrument which will furnish the elevation as well as the location of any point common to two panoramic photographs, which can be set up together in proper relation to each other and to the map. The instrument involves the use of four logarithmic spirals, which are arranged in pairs, and each pair of spirals will serve to register upon graduated drums the difference of elevation between the stations and the point; a traveling pencil will indicate the position of the point. The work which will thus be done is the solution of the equation

$$\text{Difference in elevation} = \frac{VD}{F}$$

as explained under the heading "Elevation computer" (p. 56). It is furthermore expected that, to a slight extent, contours can be traced directly with the instrument and that outlines of bodies of water and courses of streams can be obtained very rapidly.

OFFICE WORK.

PREPARATION OF MAP SHEETS.

The map is compiled either on the field sheets or on fresh sheets. If considerable sketching has been done in the field it will be more satisfactory to complete the map on the field sheets unless local errors in the plotting of the stations are found to exist in the scheme of horizontal control. It will not be necessary to replot the control points if the error is merely one of scale, for the maps are published on a reduced scale, and any consistent error can be taken into account in the reduction process. If opaque celluloid has been used in the field the compilation is usually made on fresh sheets of double-mounted calendered paper. It is desirable, though not necessary, to have the map on a single sheet. A size greater than 24 by 36 inches is inconvenient to handle, so the office sheets used are not larger than those dimensions. The triangulation points are plotted and all the necessary elevations computed before the work on the photographs is commenced.

The map projection, which consists of the latitude and longitude lines, may be drawn on the sheets either before or after the map has been compiled, but it is more satisfactory to have it done in advance of the compilation, chiefly because of the aid which the projection

lines give in the plotting of control points and because of the contraction or expansion likely to take place while the map is being drawn, which would necessitate a computation of projection values for an irrational scale.

PREPARATION OF THE PHOTOGRAPHS.

Contact prints are made from the negatives on sheets large enough to allow sufficient margin at the edges for them to be trimmed to the size necessary for use in the photo-alidade. The trimming is done with a sharp knife on a glass plate. A second glass plate is employed for the double purpose of regulating the size of the photographs when trimmed and of supplying straight edges for cutting. It is of the dimensions desired for the photographs and has smooth, parallel edges. It also carries marks which serve as guide lines in placing it over the untrimmed photograph. The photographs are trimmed and then labeled with their proper station numbers. A group is selected for immediate work, and these photographs are compared to identify and mark the control points and numerous other points common to two or more of them. The amount of marking necessary will depend on the scale of the map and the character of the topography. The photographs are then ready for use in the photo-alidade and the rotary scale.

The film must be in uniformly close contact with the paper in printing and the timing must be as nearly correct as possible. The printing should therefore be done by one who is skillful in judging the capacity of the negatives. Several photographs should be tested for dimensions to make sure that the contraction has been uniformly distributed, and warped prints should be discarded. Under uniform atmospheric conditions photographs from a single camera measure closely to an average size, so that if the contour interval is not small a common focal length may be used for the set without introducing errors large enough to interfere with the proper placing of contours.

For convenience in work and consistency in dimensions "printing out" papers which are unglazed or only slightly glazed have been found most satisfactory. The paper should be fairly heavy and of a kind that can be dried without "squeegeeing." An examination of many photographs gave a maximum variation between length and width of 0.5 per cent and an average of 0.1 per cent. The changes in print sizes may therefore be considered as uniform, and the decrease in width will be practically proportional to the decrease in length.

USE OF THE PHOTO-ALIDADE.

The requirements necessary for the use of the photographs are (1) that the camera station and the direction to at least one point in a photograph must be previously ascertained, or (2) that if the position of the camera is unknown, four or five known points must be included in a set of photographs taken at one station. The photo-alidade, therefore, in the second contingency, serves to locate the position of the station. For the location of the station from the photographs the known points should be distributed around the horizon, though a location can be satisfactorily obtained from one photograph if the position of the camera is favorable with respect to the known points. The locations are made on sheets of transparent celluloid, so that the method is merely an adaptation of the well-known tracing-paper method.

When the position of the station has been determined, a photograph is adjusted in the frame of the photo-alidade, as shown in Plate VIII, and a known point is sighted. The instrument is then centered over the station and the edge of the revolving arm is brought into line with the direction of the point sighted. The photograph will now be in orientation on the map, and the marked points are sighted in order that lines may be drawn in their directions. The lines are labeled to correspond with the marks on the photographs. Companion photographs from other stations supply the cross lines for intersection, just as in the plane-table method.

The accuracy of the position of a station when determined from the photographs is quite sufficient for all local work, for it is of about the same degree as that obtained with an open-sight alidade in the field, but positions of stations should not be relied upon for extension of control. The points in the photographs sighted for the location of stations should be well defined. One of them should be far enough away to establish a satisfactory orientation. The photographs used for obtaining the position of a station should be taken from the same spot.

Plate X shows a traverse of a shore line which was mapped from the accompanying photograph. The position and elevation of the camera above the bay were determined in the field. The photograph was set up in the photo-alidade, so that the directions to numerous points could be drawn. At the same time a duplicate photograph was used in the rotary scale (Pl. IX, p. 56) to supply the vertical factors of the points as they were sighted in the photo-alidade. The elevation computer (fig. 7) then supplied the distances, which were plotted as the sights were taken. In this use of the photograph the reverse of the process of obtaining differences of elevation was employed—that is, the vertical factors as obtained from the photo-

graph and the difference in elevation being known, the rotary scale was manipulated with respect to these two known quantities to supply the distances.

In Plate X the photograph is placed near the traverse rather than in the photo-alidade in order to show better its relation to the shore line as mapped. Certain points are labeled on both the photograph and map in order that the connection may be easily followed. If the difference of elevation between the station and the point sought is as great as 600 feet to the mile, corresponding to an angle of depression of about 6°, this method supplies distances sufficiently accurate for the scale of 1:48,000.

The triangles indicate stations for control that were occupied with the plane table, and the tangent lines represent sights that were taken from them. These lines supply a measure of the accuracy of the traverse of the shore line. As a further test the shore line as traversed by the United States Coast and Geodetic Survey on a scale of 1:40,000 is shown in Plate X, reduced to the scale of 1:48,000, beside the line obtained from the photograph.

DETERMINATION OF ELEVATIONS.

Table 8 is a sample of the form in which the notes for determining elevations are kept. The focal length of the photograph is given in the first column and the station number in the second. The third column indicates the points upon which readings are to be made. Readings from the rotary scale are entered in the fourth column and the distances taken from the map in the fifth column. From these quantities the differences of elevation, which require correction for curvature and refraction, are obtained by means of the elevation computer.

The results shown in the table indicate the degree of accuracy obtainable from the photographs. The variations of the sets of elevations are due principally to the fact that the measurements are made without the aid of precise micrometers.

TABLE 8.—*Notes on elevations obtained from photographs.*

Focal length of photograph.	Station from which photograph was taken.	Label of point read upon.	Vertical factor, measured from horizon line of photograph to image of point read upon.	Distance of point from station.	Apparent difference of elevation.	Correction for curvature and refraction (+).	Corrected difference of elevation.	Elevation of station as corrected.	Mean elevation.
Inches.			*Inch.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
5.32	9		0.170	4.11	690	14	704	3,995	
5.32	8	4-7	.420	3.85	1,600	13	1,613	4,013	4,006
5.32	12		.290	4.99	1,430	19	1,449	4,010	
5.32	9		.120	3.77	450	13	463	3,754	
5.32	8	4-8	.390	3.50	1,350	12	1,362	3,762	3,768
5.32	12		.270	4.50	1,210	16	1,226	3,787	
5.32	9	4-9	.125	3.34	410	11	421	3,712	
5.32	8		.440	3.05	1,330	10	1,340	3,740	3,735
5.32	12		.300	3.96	1,180	13	1,193	3,754	
5.32	9		.185	5.51	1,010	22	1,032	4,323	
5.32	8	4-10	.375	5.21	1,940	20	1,960	4,360	4,338
5.32	12		.315	5.60	1,750	22	1,772	4,333	
5.32	34		.110	5.55	600	22	622	6,432	
5.32	32		−.75	14.20	−1,055	120	−935	6,245	
5.32	38	Sta. 35	.190	10.10	1,800	63	1,863	6,235	[a]6,313
5.32	39		.155	16.06	2,465	152	2,617	6,350	
5.32	23		.30	15.90	470	150	620	6,304	
5.33	52	Sta. 65	.050	9.15	450	52	502	3,909	
5.33	52	Sta. 55	.260	6.30	1,620	27	1,647	3,896	
5.33	52	Sta. 70	.085	11.70	990	83	1,073	3,866	
5.33	52	Sta. 50	.035	8.95	310	50	360	3,880	[b]3,902
5.33	52	Sta. 17	.300	5.60	1,660	22	1,682	3,924	
5.33	52	Wick.	.135	13.46	1,800	109	1,909	3,921	
5.33	52	Sta. 48	.120	11.55	1,370	81	1,451	3,909	

[a] Elevation of station 35 as determined by telescopic alidade, 6,320 feet.
[b] Elevation of station 52 as determined by telescopic alidade, 3,906 feet.

The application of the method is illustrated by the map shown in Plate XI and the photograph shown in Plate XII, labeled "Sta. 60." If the distance, D, from station 60 to any point, as that marked *d*, is scaled and the vertical factor, V, obtained by measuring the height of the point above the horizon line (indicated by the horizontal lines of the notches), a calculation may be made to determine the elevation of the peak by using the formula

$$\text{Difference in elevation} = \frac{VD}{F}$$

The elevation of station 60 is 3,408 feet, V measures 0.80 inch, D scales 3.57 miles, and F is 5.32 inches, whence

$$\text{Difference in elevation} = \frac{\frac{0.80}{12} \times 3.57 \times 5280}{\frac{5.32}{12}} = 2,830$$

Calculation of elevation of point sighted.

	Feet.
Difference in elevation obtained from photograph	2, 830
Correction for curvature and refraction	12
True difference of elevation	2, 842
Elevation of station 60	3, 408
Elevation of peak "*d*"	6, 250

ADJUSTMENT OF TRAVERSES.

Traverses may be adjusted to the map either in the field or in the office if they are on the same scale as the map, but if they are on a different scale it will be more satisfactory to adjust them in the office. In surveys on the larger scale the traverses are run on the scale of the map, but in reconnaissance surveys it is more convenient to run the traverses on a scale greater than the scale of the map. For instance, if the station work is done on the scale of 1 : 180,000, the scale of 1 : 90,000 is used for the traverses. It is then necessary to reduce the traverses to the scale of the map, and this is ordinarily done by photography or the pantograph, photography being used if the traverses are extensive. Distances between known points common to both map and traverse sheets, rather than the nominal scales, are used to determine the amount of reduction. In the "celluloid transfer," now largely in use, carbon images of the traverse lines are printed on thin, transparent celluloid in such a way that they may be transferred rapidly to the map by burnishing. This is done by photography and has great value because of its accuracy and rapidity. Lines thus transferred to the map appear much like pencil lines and are inked with the rest of the map.

CONSTRUCTION OF CONTOURS.

All the topographic mapping that has so far been done by the United States Geological Survey with the aid of the panoramic camera has followed the usual course, in which the topographer at the end of the field season takes up in the office the compilation and drafting of the finished map. The practice of allowing the topographer to carry his work through the proof reading has been found desirable in plane-table surveys. It is not likely that another draftsman could compile a map from photographs with as good results as the man who did the field work. At any rate, training in topographic expression will be imperative in the office work. Therefore, although in a measure the method simplifies and reduces the field work, it requires considerable topographic skill to extract the data from the photographs and to sketch accurately the forms on the map. Sketching contours from photographs differs very little from sketching in the field. The best opportunity for contrasting sketching from photo-

graphs with field sketching is afforded by the degree of dependence which must be put upon the eye in placing contours along slopes. In field sketching, where a station is occupied once, or rarely more than once, the eye must be relied upon to a far greater degree in placing minor features than in sketching when photographs may be examined in any matter of detail whatever.

In compiling data from photographs it has been found best to concentrate upon a small area and to complete that area before taking up another. The elevation notes are kept conveniently at hand to supply the elevations, and the photographs are examined again and again in order that the forms may be correctly represented. Drainage should be drawn before the contouring is commenced. No rules for the drawing of the contours will be given here, for it is largely a matter of skill in draftsmanship that can be acquired only by practice.

In order to illustrate the use of the photographs in sketching contours a portion of the Port Valdez map (Pl. XI) and photographs (Pls. XII and XIII), used in sketching areas on the map, have been given to show the relations of the photographs to the map. A portion of the Broad Pass map (Pl. XIV) and also a series of views (Pl. XV) are given for the same purpose. The positions of the stations, the angular scope of the photographs, and a few prominent peaks are marked on the maps, and the corresponding points are labeled on the photographs.

THE APPLICATION OF PHOTOGRAMMETRY TO AERIAL SURVEYS.

INTRODUCTION.

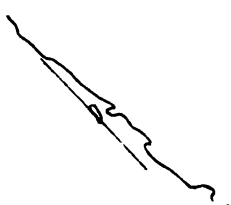
The purpose of these suggestions is to indicate methods for the employment of aerial photographs in making military reconnaissances. The object to be accomplished is to determine the values of horizontal and vertical distances over a terrane of moderate extent.

The survey of a district by methods of aerial photography, as in the older methods, involves the measurement of a base and of horizontal and vertical angles and the determination of certain station positions in order that other distances and elevations may be determined. The procedure of aerial photography consists of (1) the measurement of a base, (2) the exposure of the negatives (corresponding to instrumental observations of other methods), (3) the establishment of the positions of the photographic (aerial) stations, and (4) the work of intersection and determination of elevations from the photographic negatives.

In the discussions that follow five cases are considered. Four of these fall under the general head of district reconnaissances and one under the head of rapid route reconnaissance. Under case 1 is pointed out the method by which an aerial reconnaissance of considerable precision may be made, and under case 2 a method that should permit the determination of comparatively long distances with a fair degree of accuracy. Case 3 suggests a possible working method for the employment of photographs obtained with a minimum photographic equipment. Case 4 treats of a method which, though of only relative accuracy, yet, on account of its facility of application, may prove of considerable value. The suggestions for rapid route reconnaissances are probably already well known to aviators who have had experience in taking photographs of the ground beneath them during flight in airplanes. Photographs taken with the optical axis of the camera directed down from positions over relatively flat country should supply maps of great reliability, provided proper means are employed to determine the variation of the optical axis from the vertical line.

GENERAL CONDITIONS.

At the outset it is well to discuss briefly the degree of precision that can be expected from photographic negatives exposed for the purpose of making measurements. Recent tests have proved that the anastigmatic lens will produce a sensibly true perspective and



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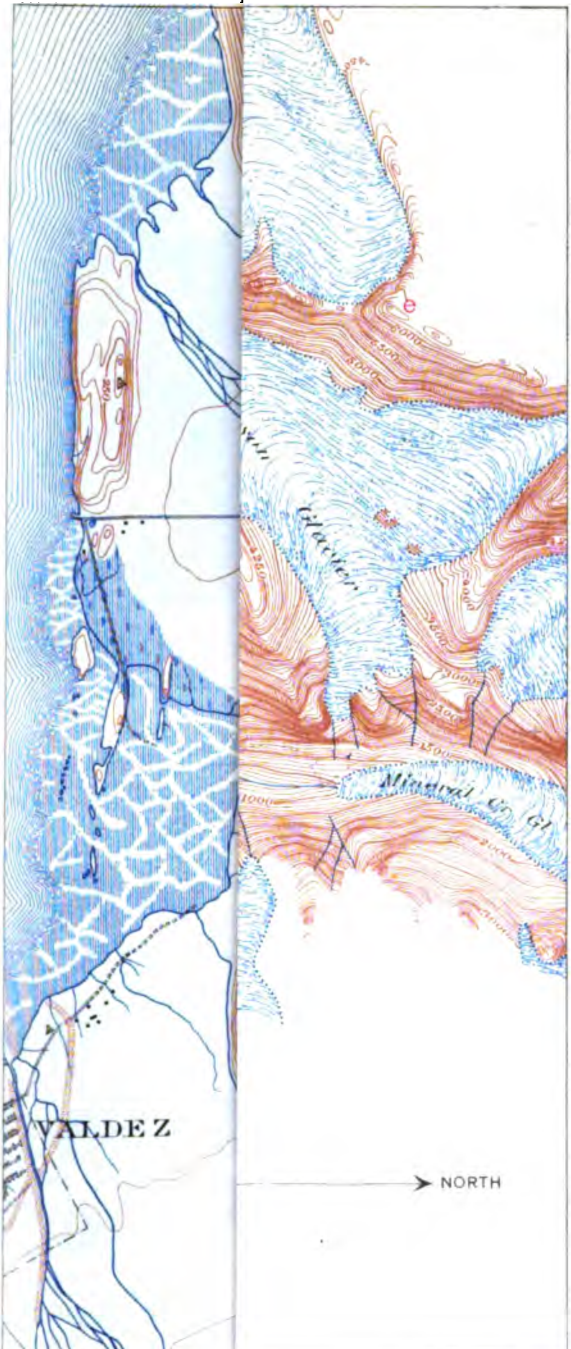
MAP SHOWIN SAME AREA BY THE UNITED STATES COAST



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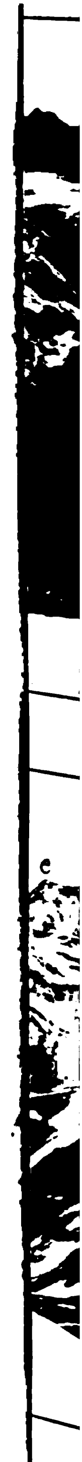
Red lines indicate horizontal scope of photographs



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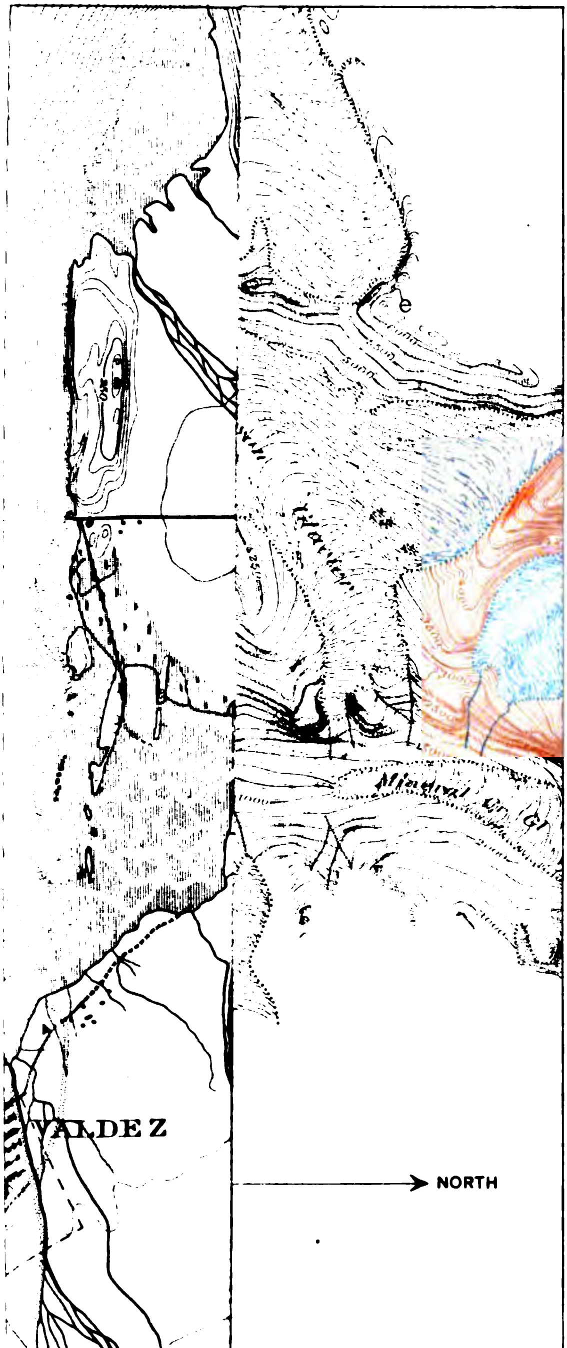

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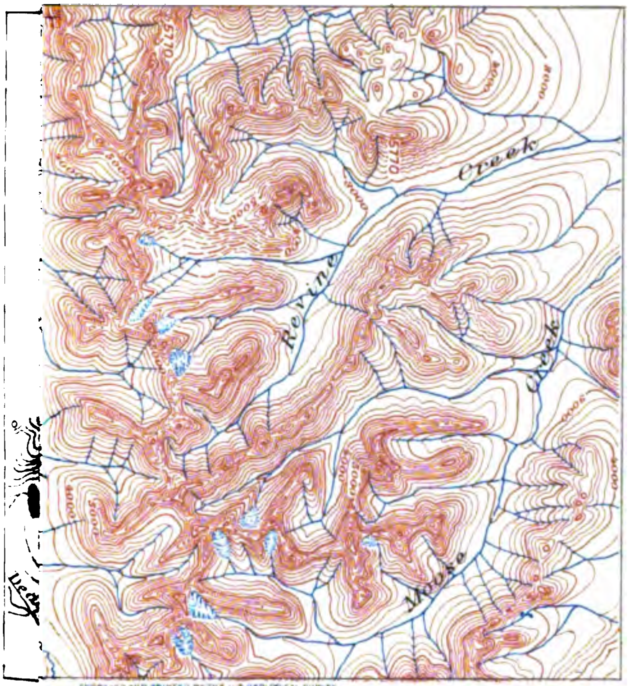

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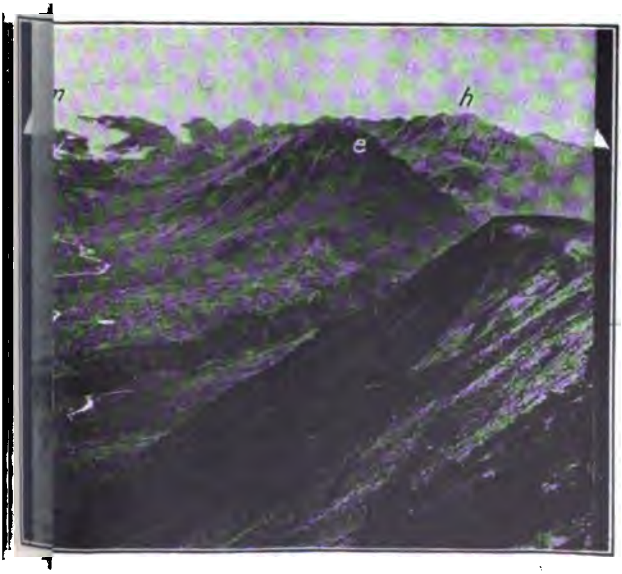
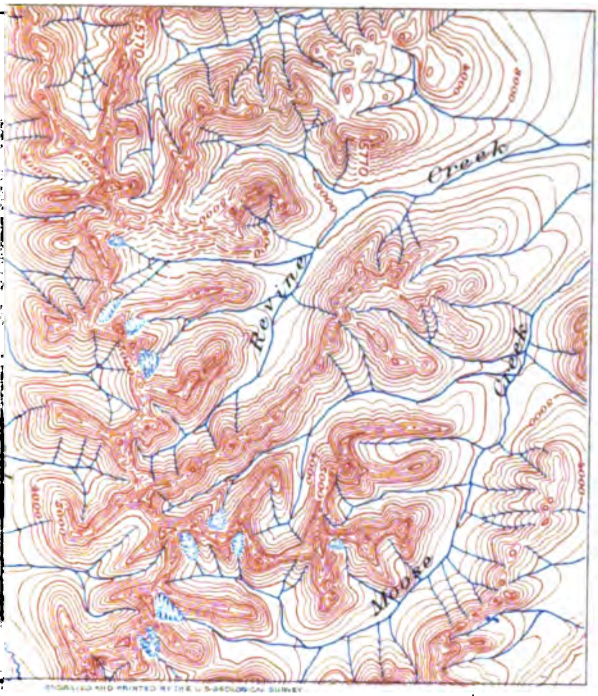
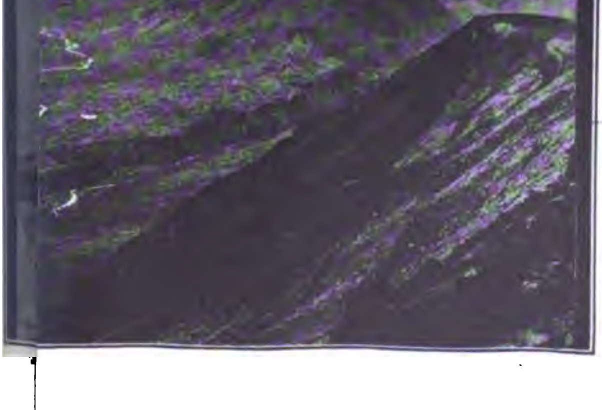




Red lines indicate horizontal scope of photographs



that a camera can be constructed with its parts assembled in as nearly mathematically correct relation to one another as the parts of a telescopic instrument employing a similar lens, provided the same degree of care is given. The question is therefore resolved into this: What error will be introduced in the calculation of an angle from ordinates measured on a photographic negative? It is evident that this error will depend on the error arising in measuring the ordinate, the focal length of the lens employed, and the error in determining the angle of inclination of the negative.

In photogrammetry the reference planes are properly the horizontal plane passing through the optical center of the lens and the vertical plane containing the optical axis. The angle of inclination is the angle that the optical axis makes with the horizontal plane, so that if a is the angle between two points to be measured in a horizontal plane, b the angle of inclination, f the focal length of the lens, and x the horizontal ordinate measured on the negative we shall have

$$\tan a = \frac{x}{f \cos b}$$

whence

$$da = \frac{f \cos b}{f^2 \cos^2 b + x^2}\, dx$$

Without going into the differentials of this equation with respect to each of the quantities appearing, it will suffice to state that they indicate certain conditions to be avoided as well as the conditions that are conducive to accuracy. The conclusions may be stated thus:

1. The error brought to a through the measurement of x decreases as x increases—that is, the greater the angle the less the relative error.

2. In general the longer the focal distance of the negative the less the error in a. For negatives inclined near to a horizontal position x may approach a value equal to $f \cos b$. This condition renders the determination uncertain. The condition corresponds to that when both x and $f \cos b$ are small.

3. The maximum error due to the influence of the inclination may be expected when $\cos b = \frac{x}{f}$.

Negatives obtained from aircraft are subject to still other errors, which are due to the displacement of the vehicle during the time of exposure and to the angular motion of the camera.

If we assume that the speed of the machine will not exceed 100 miles an hour (147 feet a second) during exposure and that a displacement of 1 foot is allowable, the greatest time of exposure should not exceed 1/150 second. For a stop of F 6.3 in bright weather this time may be reduced to 1/600 second, which is sufficient to assure rigorous precision.

The allowable angular movement of the camera may be determined from the requirements to give sharp definition in image. Simple means of making measurements from negatives impose a limit to definition of image of 0.1 millimeter. For a lens of 12-inch (305-millimeter) focus a movement of 0.1 millimeter in image during the interval of 1/150 second corresponds to an angular movement of about 1′. For work of precision it is therefore necessary to assure a practical elimination of angular movement. The value of 1′ of arc affords a measure of the accuracy to be expected from photographic measurements when the necessary precautions are taken in doing the field work. It corresponds to about 1.5 feet in a mile, or 15 feet in 10 miles.

Finally, there is to be considered the error which has its source in the means of establishing the position from which the photograph was taken and of connecting this position with known positions on the ground. It is plain that if the degree of precision indicated by the foregoing statements is not to be lost, means for accurately establishing the camera's position must be adopted, The obvious method of observing the camera's position from three or more stations on the ground will not suffice to determine this position unless the observations are made photographically, an electric current being used to assure a simultaneous exposure of four cameras. This requirement, which is at present impracticable of accomplishment, eliminates the possibility of using this method. A method that affords a practical and comparatively simple means of locating the camera's position is that of photographing a measured base at the instant of obtaining the photograph of the region to be surveyed. In this manner the error introduced will be no greater than that inherent in photogrammetry or that arising from the measurement of the base.

Systems of triangulation made up of stations suitably disposed eliminate the necessity of laying out a base. This condition may for the present, however, be excluded from consideration, for in those regions where a triangulation net has been established maps will most probably have already been prepared.

THE BASE.

The form of the base will vary according to the requirements of the survey or the time available to lay it out. The form which is most suitable is illustrated by figure 8. At each end of a carefully measured base line, AD, an equilateral triangle is measured on ground as nearly level as can be found. The length of AD will depend on the distance to be covered by the survey and it should be long enough to make intersections in the field of the survey at angles not less than 30°. The stations A, B, C, E, etc., are marked by white disks of a size suitable for the distance from which they are to be photographed.

The stations are also connected by a line of levels. As a check upon intersections a third triangle may be measured near the middle of AD. This will be used when photographs from three positions are required for the survey.

The aviator flies above the triangles at a height sufficient to permit good views of the region to be reconnoitered. Exposure upon a triangle is made at the same instant of exposure upon the district under investigation. The negatives thus obtained may be those of

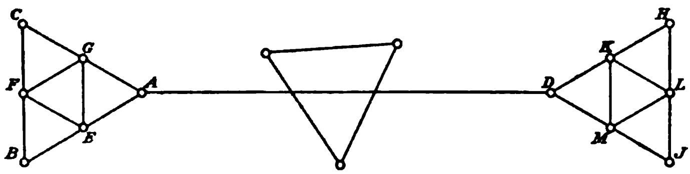


FIGURE 8.—Form of triangular base for determining positions of aerial photographic stations.

a single camera or of a combination of two cameras. The different arrangements of cameras will be discussed under the cases to be considered. The image of the triangle serves to supply the position and elevation of the "station."

When the distance to be covered by the reconnaissance is not great, and for special arrangements of the cameras, the whole system of the base may be reduced to a single triangular figure. This use will be mentioned under the several cases.

SPECIAL LEVELING DEVICES.

JARDINET TUBE.

In order that the angle of inclination of negatives taken in an approximately vertical position may be known, it is necessary that the position of the horizon line be determined. This may be obtained from the equilateral figure mentioned or by means of the Jardinet tube, a contrivance designed for the purpose. The Jardinet tube seems to be well adapted to balloon use, but on account of the complication of centrifugal forces there is doubt as to its applicability to use in airplanes. Figure 9 shows the arrangement of this device. It consists of a system of parallel closed tubes joined by other tubes, in which is contained a quantity of mercury. Two branches of the main tubes have enlarged sections, so that the center of the total surface of the mercury, which remains at a constant distance from the plane of the bottom, will be shifted to a point near the plane of the enlarged tubes. In this way the distance between the two principal planes AB and CD may be divided by the center point of the surface into parts having a ratio such as 1 to 10 or 1 to 12, the ratio being ascertained by a calculation.

The tube should be calculated and constructed to conform with the focal length of the lens to be employed. The tubes of uniform section are placed in contact with the plate and the enlarged sections occupy positions such that the center of the surface blends with the

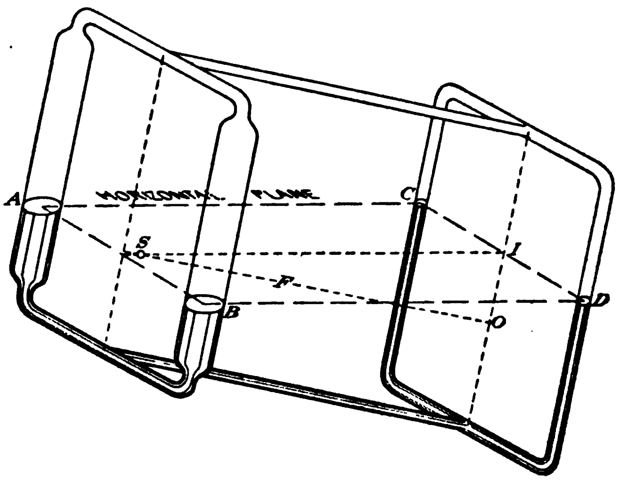


FIGURE 9.—Jardinet tube. (From Saconney's Métrophotographie.)

optical center of the lens. The shadowgraphs of the mercury surfaces supply the horizon line. Cameras that are intended for exposure in a vertical position may be equipped with the Jardinet tube.

UNIVERSAL LEVEL.

For horizontal negatives (obtained with the optical axis of the lens directed down) the universal level bubble may be adopted to supply the angle of inclination. In this device, too, as in all forms of gravity levels, centrifugal forces will be likely to introduce errors. It will be necessary that the spherical sector of the level subtend an angle wide enough to embrace the range of oscillation of the camera—as much as 6° or 8°. The level should be mounted on the side of the camera near the back and its image will be registered photographically upon the plate at the time of exposure. For this it will be necessary to employ a small lens and two prisms as shown in figure 10. The surface of the level should be checkered by lines which will be photographed at the time of the bubble. The position of the bubble with reference to the checkered pattern indicates the angle of inclination. It is necessary to employ a focal-plane shutter.

FILMS, PLATES, AND COLOR SCREENS.

On account of the necessity of making instantaneous exposures with moving cameras the flat field camera seems at present to be the only type suitable for aerial photography intended for metric use.

By reason of their liability to buckling roll films should be used only in cameras of the smaller sizes, and even in those film negatives can not be relied upon for precise measurements. It will probably be safe to use films only for rapid route reconnaissances, in which precision in measurements is not of the first importance.

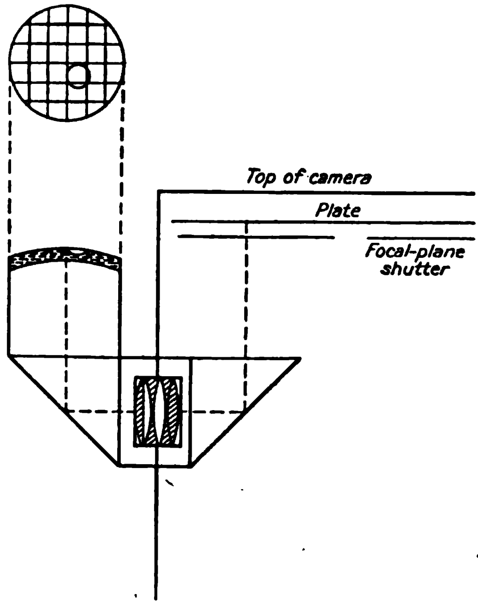


FIGURE 10.—Arrangement of universal level on camera. (After Capt. Ulyanine.)

The plates to be used should be the most rapid panchromatic plates available. They should be so selected that the negative may register details ranging through a great variety of colors and distances, and that the use of color screens may not seriously impair their rapidity. In fact, the plates and color screens should be selected together in order to obtain the best results. Such a combination as the Wratten panchromatic plate and the K_3 color screen is one of the most efficient obtainable. The color screen should be such as will equalize the actinic power of the colors of the spectrum.

DISTRICT RECONNAISSANCES FROM AIRPLANES.

CASE 1. PRECISE SURVEY.

GENERAL CONDITIONS.

The purpose in the case to be first considered is to determine with precision, from the known positions of certain points, the positions of points lying in an inaccessible district. The procedure consists in establishing the positions of aerial stations from which the points to be determined may be photographed and then located. The most precise method of accomplishing this from aircraft is that in which two joined cameras are employed, one of which establishes the position of the cameras and the other supplies the negatives covering the district to be reconnoitered. The most satisfactory arrangement of the cameras will be that in which one is pointed down and the other horizontally, the two optical axes being set exactly at right angles. This arrangement requires a base with two or more triangular figures above which the photographs will be taken. The

length of the base will depend on the distances to be measured; the size of the triangles will depend on the height at which the photographs are to be taken. The focal length of the principal camera will likewise depend on the distance to be covered and the limit to the size of objects to be located. In the discussion that follows it is assumed that the maximum distances to be measured will not exceed the range of heavy field artillery—6 or 7 miles. For greater distances the reconnaissance may be made either by increasing the focal length of the principal camera or by changing the arrangement of the cameras, as described under case 2.

PHOTOGRAPHIC EQUIPMENT.

At 7 miles the scale of the photographic image will be $\frac{f \text{ (in inches)}}{12 \times 5280 \times 7.}$ Therefore, if the lens has a focal length of 12 inches, the scale will be approximately 1:37,000; for a focal length of 24 inches, about 1:18,500. The scale of 1:37,000 will permit the identification of objects as small as 30 feet in greatest dimension; that of 1:18,500, objects as small as 15 feet. These figures give a measure of the accuracy of the method, provided the base is laid out with care.

The principal camera should conform with the figures just given according to the requirements of the work it is to do. The lens should be an anastigmat, free of distortion through an angle of 30° from the optical axis, and it should work with a wide aperture. The camera should be constructed of aluminum upon a rigid frame and should be equipped with centering marks and a focal-plane shutter permitting an exposure as rapid as 1/600 second. It may be desirable to include the Jardinet tube, though this device is not necessary in the procedure under discussion.

If the lens of 12-inch focus is used, plates measuring 10 by 14 inches will give a field of about 45° by 60°. A plate of the same size in a camera of 24-inch focus will give a field one-half as large. The lens should be so placed as to shift the optical center of the negative to a point about halfway between the middle and lower edge of the negative. The size of the plate will probably be limited by the facilities for handling the camera in the machine. Exposure will be made by a release that actuates the shutter of the principal camera simultaneously with that of the auxiliary camera.

The auxiliary camera will be of 6-inch focus and give a 6 by 6 inch negative whose field embraces an angle of nearly 60°. It will be equipped with an anastigmatic lens, focal-plane shutter permitting an exposure at 1/600 second, centering marks, and release joined with that of the principal camera, and it will be fastened to the principal camera so that the optical axis of one camera will lie in the principal plane of the other and the two optical axes form an angle of 90°.

The two cameras, which thus form a single photographic instrument, may require a special aimer to permit pointings in the two directions. This aimer (fig. 11) consists of two frames delimiting the fields of the cameras, a mirror, and an eyepiece, and may be attached to the instrument. The frame corresponding to the field of the principal camera should have cross wires indicating the horizon line and a center line perpendicular to the horizon line. Exposures will be made with these wires resting as closely as possible upon the apparent horizon and the center of the district to be photographed,

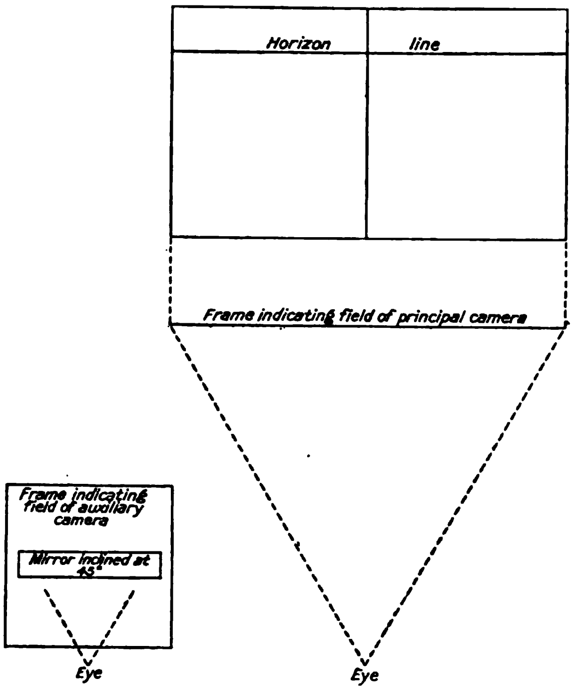


FIGURE 11.—Arrangement of camera aimer.

respectively. The instrument may be suspended by a strap (elastic if the vibrations of the motor require it), and it should have a handle for making pointings.

CONTROL.

The negatives will be controlled by means of equilateral triangular figures tied together by a measured base. The targets forming such a triangular figure should lie sensibly in the same plane, for the reason that by imposing this condition the work of locating the photographic station will be greatly simplified and reduced. The size of a triangle should be such that its photographic image will cover more than half the negative. The length of each side of the

triangles should therefore be approximately two-thirds the elevation of the cameras above the ground.

The position of the photographic station and its elevation with respect to the base may be determined from the image of the figure (auxiliary negative). This image also supplies the orientation of the principal camera with respect to the base. The angle of inclination is likewise supplied by the image of the equilateral figure. This may

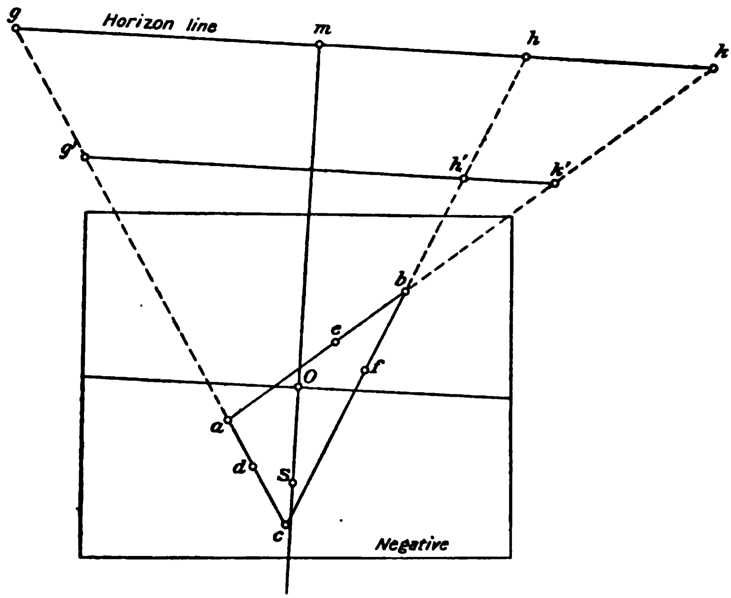


FIGURE 12.—Determination of horizon line and station point of negative.

be taken directly from the principal negative if the camera has been equipped with the Jardinet tube.

If *a*, *b*, *c*, *d*, *e*, *f*, figure 12, represent the images of targets (auxiliary negative) forming four equal equilateral triangles, the horizon line may be found as follows:

Prolong *ac*, *ab*, and *cb*. From the relation existing between harmonical conjugates of perspectives the horizon line may be found by taking a distance

$$ag = \frac{ac \times ad}{dc - ad}$$

$$bk = \frac{ab \times eb}{ae - eb}$$

and

$$bh = \frac{bc \times bf}{cf - bf}$$

Then the line *ghk* represents the horizon line.

From the optical center of the negative draw the line Om perpendicular to the horizon line. The angle of inclination b follows from the relation $\tan b = \frac{f}{Om}$, f being the focal length for the negative.

When the auxiliary negative is only slightly inclined from a horizontal position the horizon line will fall at a great distance outside the limits of the negative. The distance Om may then be found by taking distances as cg' and ch' proportional to cg, ch to supply a line $g'h'k'$ parallel to the horizon line. The direction of Om will result, and a calculation can be made to determine its length.

The position of S (the point of the negative which indicates the projection of the photographic station upon the ground plane) is established from the relation

$$oS = \frac{f^2}{Om}$$

In order to locate upon a drawing the position of the photographic station with respect to the plotted positions of the targets proceed as follows:

Having determined on the negative (fig. 12) the position of S by the method just explained, from s on a tracing of the negative or a positive

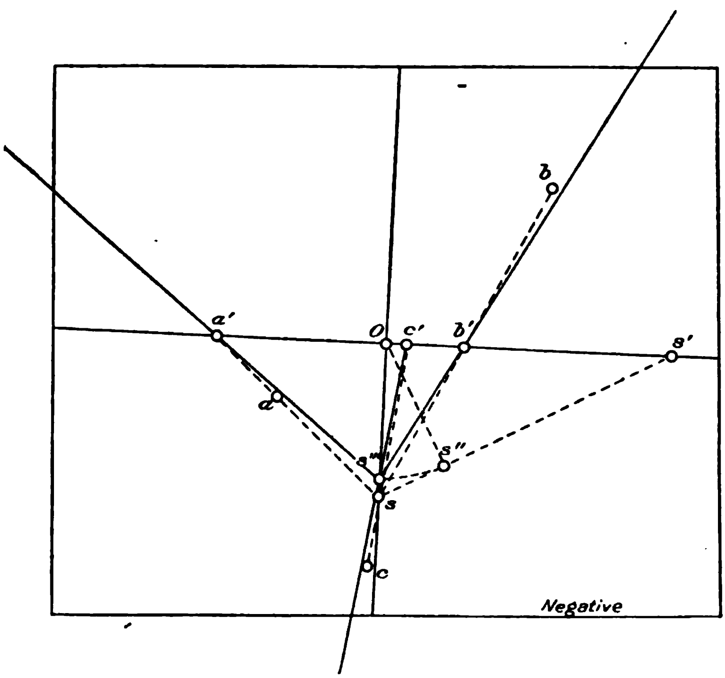


FIGURE 13.—Determination of station position.

print (fig. 13) draw lines through each of the points a, b, c, to meet the horizontal line through O at a', b', c', respectively. Lay off a dis-

tance Os' equal to the focal length of the negative. Connect s with s', and let fall upon ss' a perpendicular Os'' from O. Take Os''' equal to Os'' and then draw from s''' lines through the three points a', b', c'. These lines supply the horizontal angles formed at the photographic station by lines to the targets.

ORIENTATION.

The orientation of the principal negative results from the orientation of the auxiliary negative. In relying upon this method of orientation there will be conditions under which the angles at the point s''' (fig. 13) will necessarily have to be determined by lines of relatively short lengths, which render the orientation unreliable. In order to assure a precise orientation it will be desirable to determine by intersection from the base the position of one or more points lying in the field embraced by the vertical negatives.

THE SURVEY.

Such a photographic survey from aircraft as the one under discussion may be considered as consisting of four different steps—(1) laying out the base, (2) obtaining the photographic negatives, (3) establishing the photographic station and orienting the negatives, and (4) locating points. In order that the time required for accomplishing the work of the different steps may be reduced to a minimum the procedure should follow the course of first laying out the triangular figures and then obtaining the negatives, the work of joining the triangular figures by the base being performed while the negatives are being prepared for use and the positions of the negatives established with reference to the triangular figures. The plotting of positions of points may then be commenced as soon as the complete base has been surveyed and plotted.

The time required for the first three steps, which bring the survey to a state of preparation to commence the plotting of points, should be no more than that necessary to prepare and plot the base. Negatives can be developed in a few minutes, and measurements may be made from them immediately thereafter. The calculations for establishing the position of the photographic station require less than a dozen measurements, and the calculations themselves should require no more than an hour to complete.

The base should be laid out by chain and transit so as to assure a degree of precision no less than that possible in measurements from the negatives to be used. A precision of 1 in 5,000 or even 1 in 10,000 may be attained without greatly curtailing the speed of the work.

The triangular figures may be laid out rapidly by employing two steel tapes and building up the figure from several adjoining triangles having a length of side equal to the common length of the two tapes.

The procedure outlined in this case should be sufficient to locate the positions of prominent points over an area 3 or 4 miles wide lying at a distance of 3 to 7 miles from the base. In relatively flat country the information thus supplied might be sufficient for the purposes of control and regulation of artillery fire. In hilly country it would probably be necessary to supplement the data thus obtained by photographs taken from positions over the district of the survey with camera directed down, the supplementary photographs being controlled in position and scale by points located from the principal negatives.

CASE 2. PRECISE SURVEY.

GENERAL CONDITIONS.

The procedure in case 2 differs from that of case 1 in that two separate cameras instead of a composite instrument may be employed to give similar results. This method permits a wider latitude in the movements of the aerial vehicle, for stations may be made anywhere within certain generous limits of the base, but the difficulties of manipulating the cameras are increased, and special means of orienting the principal negatives will almost always be required. The gain over the procedure of case 1 comes from an increase in range.

The particular positions of the photographic stations that eliminate the necessity of control other than that supplied by the negatives are those from which the two negatives, auxiliary and principal, embrace common ground and in which the principal negative may be oriented by directions plotted from the auxiliary negative (fig. 14, *A* and *B*). For such use it would be convenient to have the two cameras joined in a manner that permitted them to be easily detached. As this arrangement may be considered a particular application of the general method, the discussion will be devoted to the procedure of broader scope.

PHOTOGRAPHIC EQUIPMENT.

The two cameras should be similar in design and size to the principal camera described for case 1. They should be of not less than 12-inch focus and employ plates as large as the limitations of airplanes permit. Both should be equipped with the Jardinet tube. The remaining details should conform with those mentioned for the principal camera of case 1.

CONTROL.

The system of control will consist of a number of triangulation stations (fig. 15), so disposed as to present a minimum number of three targets to the field of the auxiliary camera, from whatever position the exposures may be obtained. It will furthermore be

necessary to have at least one additional object of known position in the district to be reconnoitered, to serve for the orientation of the principal negatives. The breadth of the field covered by targets should be approximately as great as the distance from the photographic station to the nearest targets, and the farthest targets should

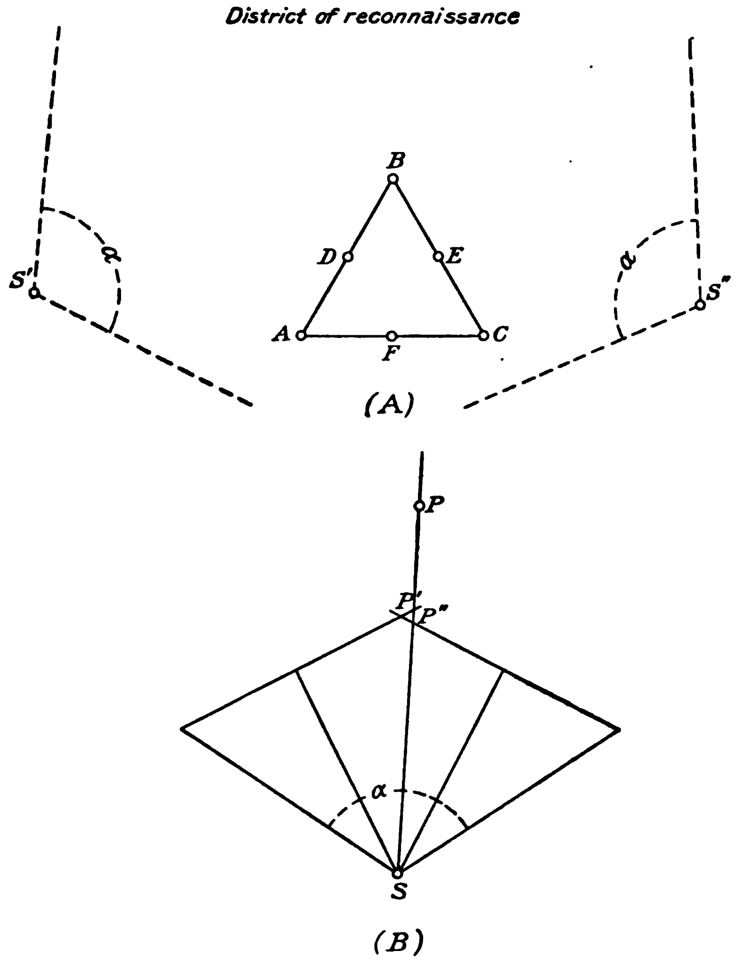


FIGURE 14.—Arrangement of two joined cameras, with plates approximately vertical.

be so placed as to stand a few miles from the nearest. The elevations of the targets must be known in order to determine the positions and elevations of the photographic stations. The targets should be of uniform design, whitened to contrast with their surroundings, and large enough to be plainly visible at the distance from which they will be photographed. Their size in feet should be about five times

the distance in miles. Advantage may be taken of buildings or other existing objects conveniently situated which may serve as targets.

OBTAINING THE PHOTOGRAPHIC NEGATIVES.

Figure 15 shows the positions of the photographic stations relative to the targets and the district to be reconnoitered that yield the greatest range. The distance between the aerial stations should be kept great enough to form a suitable base for intersection within the area of investigation.

The cameras will be exposed with the plates approximately vertical. Though it might be possible for a single operator to expose with assurance of aim the two cameras in opposite directions at the same time, it would require a skill that could not be attained except by considerable training. It is therefore probable that the manipulation of the cameras would require two operators. The exposures will be controlled by a single release.

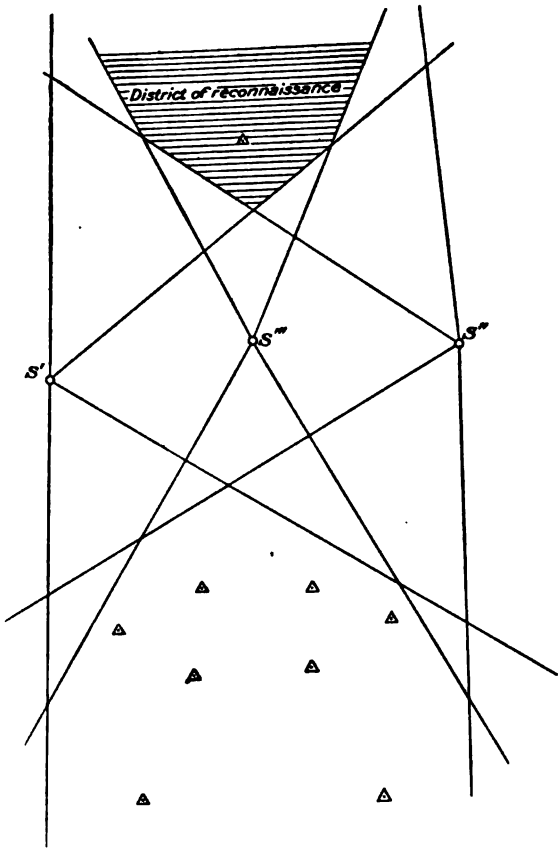


FIGURE 15.—Relation of photographic stations to targets and district of reconnaissance; two separate cameras.

ESTABLISHMENT OF THE POSITIONS OF THE PHOTOGRAPHIC STATIONS.

The positions of the photographic stations are determined from the known differences of elevation of three or more targets whose images appear in the auxiliary negatives. The accurate location of the aerial station requires a precise determination of the angle of inclination of the negative. The method consists of a series of

successive approximations gradually approaching the correct solution, in which the approximate angle of inclination is at first employed to determine the approximate distances from the photographic station to the targets, and then a new calculation is made to determine the angle of inclination. This process is repeated until it becomes evident that the error is reduced to a negligible quantity.

If in figure 16 S represents the photographic station, O the optical center of the negative, HI the horizon line, b the angle of inclination

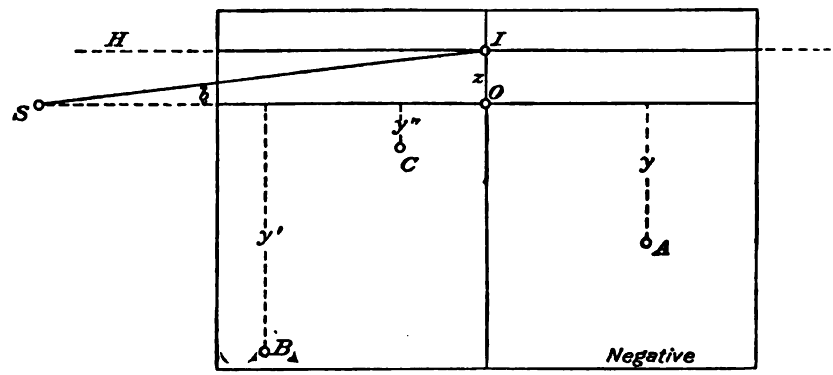


FIGURE 16.—Relation of angle of inclination of negative to elementary distances.

of the negative, SO $=f$ the focal distance, z the distance OI, and y the ordinate of any point A, we shall have $\tan b=\frac{z}{f}$.

Then if H (fig. 17) represents the elevation of the station above the known point A, and D the distance S′A′ (projection of S′A into the principal plane), the formula for determining the elevation will be

$$H=D\times\frac{z+y}{f-y\tan b}$$

If now a second point B, differing in elevation from A by an amount E, appears in the negative, we shall have for the elevation of the photographic station above B

$$H'=D'\times\frac{z+y'}{f-y'\tan b}$$

and as $E=H-H'$ we shall have

$$E=D\times\frac{z+y}{f-y\tan b}-D'\times\frac{z+y'}{f-y'\tan b}.$$

Substituting $\frac{z}{f}$ for $\tan b$ and developing the equation with respect to z we get the result

$$z^2[Eyy'+f(Dy'-D'y)]-z[Ef(y+y')+(D-D')\,(f^2-yy')]f+f^3[Ef-Dy+D'y']=O$$

which is the equation of inclination to be employed.

After having thus determined precise values for D, D′, and D″ (applying to a third point) and for z, the horizontal angles between the points may be turned off on a sheet of frosted celluloid and the station located on the map.

The angle of inclination of the principal negative must now be determined from knowledge of the difference in elevation between the photographic station and some known point included in the negative. After the angle of inclination is determined the negative

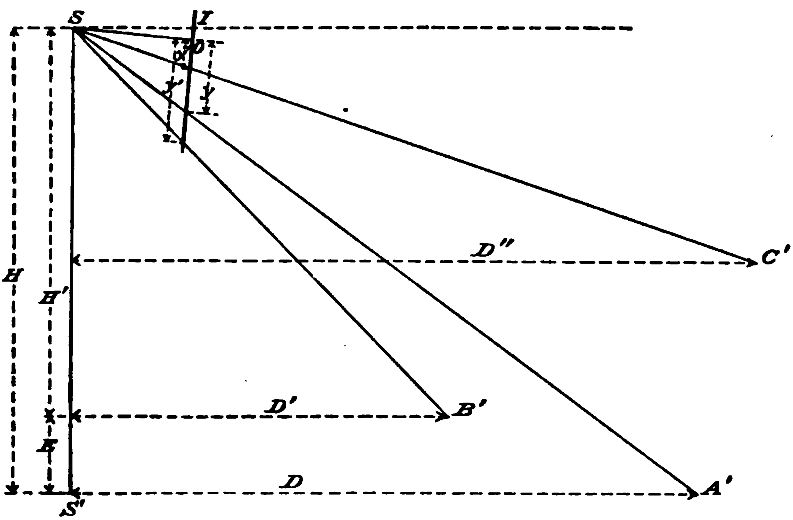


FIGURE 17.—Determination of the angle of inclination of an aerial negative from images of targets differing in elevation.

may be oriented on the map and lines drawn for intersection upon objects whose images are common to two or more negatives. Elevations may be determined by use of the formula given above.

CASE 3. MINIMUM PHOTOGRAPHIC EQUIPMENT.

GENERAL CONDITIONS.

In case 3 the minimum photographic equipment is required. A single camera may be exposed in a horizontal position (optical axis approximately horizontal) to obtain two or more negatives which shall embrace the targets of a prepared base and the region to be reconnoitered. The negatives serve in the double capacity of establishing the station positions and of supplying the information necessary for the survey. The field of usefulness of this method is narrow.

PHOTOGRAPHIC EQUIPMENT.

The lens should be capable of embracing a wide field, and its focal length should be great enough to furnish images of objects 20 feet in greatest diameter as distant as 5 miles. A rapid lens of 12-inch

focus will therefore be chosen, and it will be mounted in an aluminum box large enough to give a negative 10 by 14 inches. The lens will be so mounted as to cause the optical axis to strike the plate at a point about 3 inches from its bottom edge. The exposure will be made by means of a focal-plane shutter permitting an exposure at 1/600 second. The camera will carry an open-sight frame to outline its field of view, and the frame will have cross wires for aiming. The horizontal field of the camera will embrace 60° and the vertical field points on the ground as near as 1½ times the height of the camera. The camera may be suspended by a strap and aimed by hand. Exposures will be made with the horizontal wire of the aimer cutting the apparent horizon.

CONTROL.

The control may be obtained from one or more triangular figures as indicated in figure 8 (p. 67). If a single triangular figure is used, it will be necessary to maneuver the airplane carefully in order to be certain that the negative embraces the district of reconnaissance and the base. The triangle should therefore be laid out with appropriate length of side. The positions for exposure will be to each side and back of the figure. A third exposure may be made from a position behind the figure and in line with it and the district of reconnaissance. If two triangular figures joined by a base are used, the positions will be behind the figures and in line with the district to be surveyed.

DETERMINATION OF THE CAMERA'S POSITION.

The distance of the camera from the base and its elevation at the time of exposure will be determined by use of the perspective properties of the regular triangular figure formed by the targets. Such a determination requires at least six targets, sensibly in the same plane, forming really four joining equilateral triangles. The solution is similar to that given under case 1. For some positions of the camera the horizon line may be more rapidly determined by the procedure given below.

If a, b, c, d, e, f, in figure 18, represent the images of the targets found in the negative, the parallel lines ab and fe, cb and fd, ca and ed will meet on the horizon line, which may therefore be determined by prolonging the lines mentioned. The horizon line, which supplies the angle of inclination, b, of the negative having been determined, there remain to be found the distance between two points of the negative, forming a line parallel to the horizon line and the corresponding distance upon the ground. The line fg, parallel to the horizon line, may be drawn on the negative and measured. The actual distance FG, corresponding to fg, can be found from a drawing of the triangular base to a convenient scale by applying the principle of harmonic relations.

The line *cgeb* is laid upon the drawing of the base (fig. 19) so that each of the points mentioned except *g* falls upon its corresponding

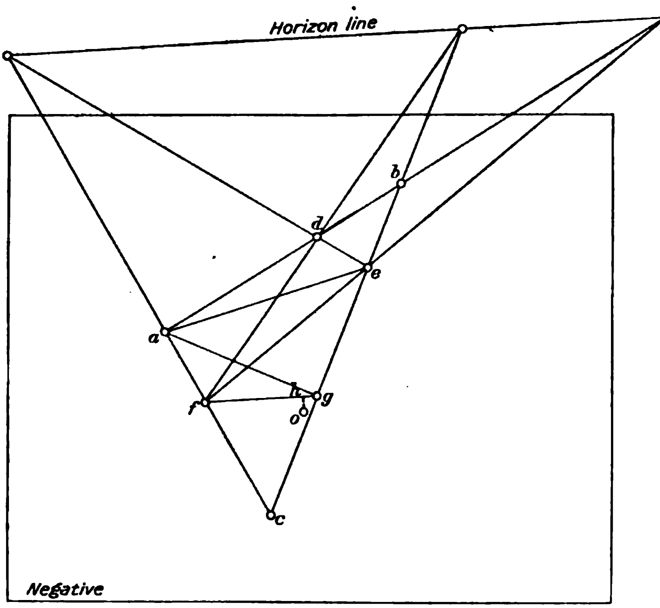


FIGURE 18.—Determination of negative line to locate position of aerial station. (From Saconney's Métrophotographie.)

line from A. The position of *g* then determines the direction of the line AG to give the point G.

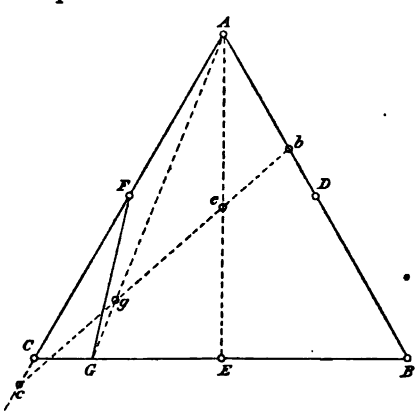


FIGURE 19.—Valuation of the line found in figure 18. (After Saconney.)

The perpendicular line from the photographic station to the line FG strikes that line at some point H, represented on the negative (figs. 18 and 20) by *h*. If, then, O is the center of the negative and

u the angle, subtended by the ordinate oh, we shall have (fig. 20) the formula for slant distance:

$$D_s = \frac{FG}{fg} \times \frac{f}{\cos u}$$

f being the camera's focal length, whence the horizontal distance is

$$Dh = \frac{FG}{fg} \times \frac{f \cos (u \pm b)}{\cos u}$$

and the difference of elevation

$$E = \frac{FG}{fg} \times \frac{f \sin (u \pm b)}{\cos u}$$

The sign of b depends on whether b is to be measured above or below the principal line SO.

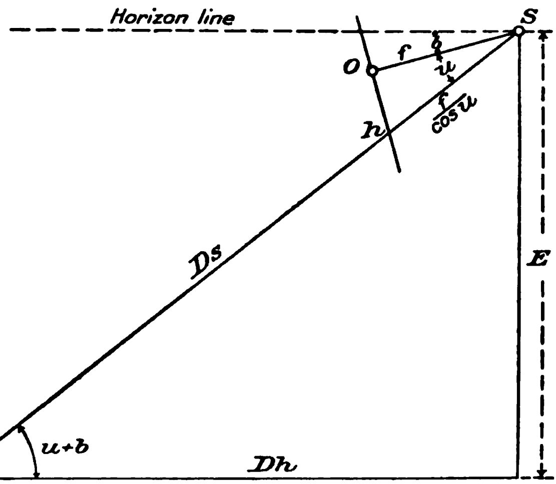


FIGURE 20.—Determination of elevation of aerial station.

CASE 4. A SINGLE CAMERA WITH A JARDINET TUBE.

GENERAL CONDITIONS.

The purpose in case 4 is to obtain the relative positions of several points in an isolated district (the survey to be made approximately to a given scale), independently of the positions of points in known territory, from photographs of the district obtained with the optical axis of the camera approximately vertical. The reconnaissance is based on the difference of elevation of the aerial stations as noted by barometer at the instants of exposure. This procedure differs from that of case 3 in that the negatives supply the horizon lines, and the relative positions of the photographic stations are determined from two points lying in a known plane (horizontal or vertical) so situated that they may be included in two or more negatives embracing the district. It is therefore necessary that the relative elevations of the aerial stations be known.

PHOTOGRAPHIC EQUIPMENT.

The camera and attachments will be similar to those described for case 3, with the addition of the Jardinet tube.

CONTROL.

It will be assumed that the barometric elevations have been noted and that the planes of the negatives were approximately vertical. The horizon line supplies the angle of inclination (b) of the negative.

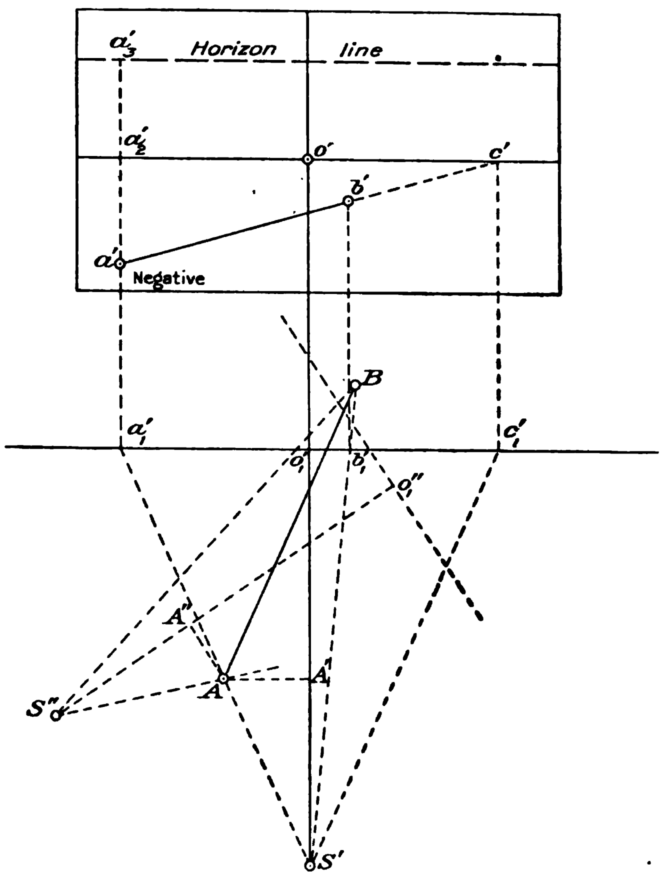


FIGURE 21.—Relative positions of photographic stations. (From Saconney's Métrophotographie.)

Two points, A and B, lying in the same horizontal plane (shore line or stream course) are found that are common to each of the negatives. The line (on the negative) connecting the images of these two points is prolonged to strike the horizon line at some point c'. The line from the optical center of the lens to the point c' is parallel to the line AB on the ground.

Lay out on a drawing (fig. 21) a line to represent the distance between A and B. From what is now known, namely, that $S'o'_1 = f$

cos b', that AB is parallel to $S'c_1'$, and that A and B fall upon the respective lines $S'a_1'$ and $S'b_1'$, the negative may be oriented with respect to AB, and by following a similar course for the second negative on a transparent sheet the relative positions of the two photographic stations S′ and S″ are ascertained.

In order to determine the scale of the drawing it is necessary to apply the barometric difference in elevation of the two stations in the formula

$$\text{Difference in elevation} = S\left(\frac{S'A' \times a'a'_3}{f - a'a'_2 \tan b'} - \frac{S''A'' \times a''a''_3}{f - a''a''_2 \tan b''}\right)$$

with reference to some point, as A, of the line AB. In the formula S represents the scale of the drawing, f the focal length of the camera, b' and b'' the angles of inclination of the respective negatives, and the remaining factors such as are indicated by figure 22 or implied for the second negative. By solving this equation for S the scale of the drawing is determined. A change to any desired scale may then be made before continuing with the work of intersections.

If a third negative is to be used, it may be oriented upon the drawing in a manner similar to that explained for the second negative.

The elevation of any located point relative to the photographic stations can be determined with a degree of accuracy commensurate with the precision obtained in establishing the difference of elevation of the photographic stations. The formula for this use is

$$\text{Difference in elevation} = \frac{DV}{f - y \tan b}$$

in which D is the projection of the distance from the station to the point upon the line of the optical axis (on the drawing), V the vertical distance (on the negative) of the point below the horizon line, f the focal length of the camera, y the ordinate of the point (vertical distance on the negative from the point to the horizontal axis passing through the optical center of the negative), and b the angle of inclination of the negative.

RAPID ROUTE RECONNAISSANCE FROM AIRPLANES (CASE 5).

ENERAL ONDITIONS.

In case 5 the camera is employed in a vertical position to obtain overlapping photographs of the country passed over in flight.

The photographic equipment necessary will depend on the altitude at which the flight is to be made and the scale desired for the resulting map. The scale of the photograph is given by the relation $\frac{f}{H}$, f being the focal length of the lens and H the height of the camera above ground. Hence, for a lens of 6-inch focus the scale at an elevation of 5,000 feet will be 1:10,000; at 10,000 feet, 1:20,000. Furthermore

there is to be considered the limit to the size of discernible objects. It may be assumed that objects whose images are less than 0.01 inch can not be easily identified on the photograph. Hence, on the scale of 1:10,000 objects less than 8 or 10 feet in greatest diameter will not show clearly, and for a scale of 1:20,000 this limit will be about 20 feet.

In this use it is essential that the lens have a wide angular range (60° to 70°), and the manipulation of the camera will be greatly simplified if film cartridges can be employed. A camera equipped with such a wide-angle lens of 6-inch focus would approach the limit of size suitable for the employment of roll film. From the foregoing considerations it would seem that a lens of about 6-inch focus would be the most suitable for the purpose.

PHOTOGRAPHIC EQUIPMENT.

The photographic equipment might therefore consist of a rapid and wide-angle lens of 150-millimeter focus mounted in an aluminum box, having a focal-plane shutter to work as rapidly as 1/600 second. The universal level may be attached to indicate approximately the deviation of the negative from the horizontal position. Marks to register shadowgraphs in the form of saw teeth will indicate the optical center of the negative. The camera could be so constructed as to permit exposures at definite intervals either automatically or by release and to accommodate a film cartridge capable of many exposures. An open-sight frame to indicate the field of the camera could be mounted on the camera or placed in a convenient position for sighting. It would be of particular value in timing the exposures while crossing hilly or mountainous country and as a rough check upon the rate of the flight.

A color screen of low factor may be used when its use would not require an exposure time greater than 1/50 second.

CONTROL.

The control of photographs obtained in flight over comparatively flat country may be obtained with a sufficient degree of accuracy by barometer readings at the instants of exposure, checked at the outset by a photograph of a measured base. Where practicable, a second base included in one of the photographs of the series may be used.

In passing from flat country, such as a valley with a large stream, to hilly country the control must be maintained by other means. This may be accomplished approximately by estimating the distance between the photographic stations from the rate of flight, the photographs being reduced in proportion to their elevation above the ground. This procedure is subject to large and irregular errors.

A method which provides a basis for calculation of the scale of photographs of rough country is to obtain the photographs from

positions differing considerably in elevation. The differences of elevation of the aerial stations should be as much as several hundred feet, and the photographs should overlap one another by as much as one-half their width. From the differences in elevation of the camera at the times of two successive exposures, as given by the barometric readings, the scale of each photograph may be determined with a degree of precision commensurate with the general degree of precision of this method of making reconnaissances.

Photographs of hilly country may be oriented by points almost directly under the camera's positions. The scale may be established as follows: Draw the line *ab* (fig. 22) representing a distance between two points, A, B, which are so chosen that they lie as nearly as possible directly below the positions of the camera at the instants of

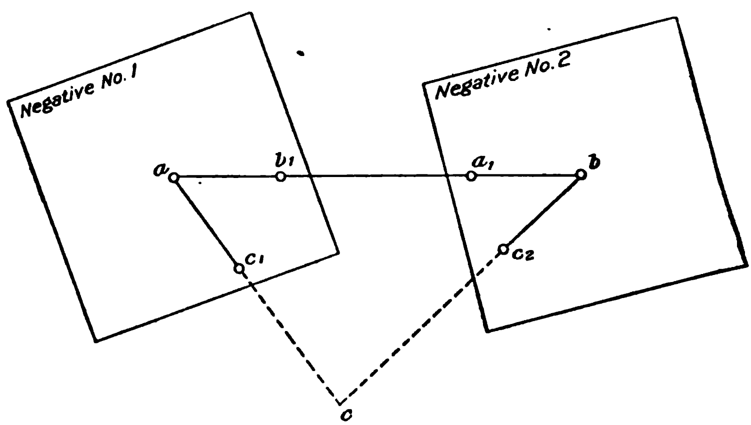


FIGURE 22.—Determination of scale of photographs; negatives approximately horizontal.

exposure of the respective negatives. Prolong ac_1 to meet bc_2 prolonged at c, the relative position of any third point, C. If then f represents the focal length of the camera, E the barometric difference of elevation of the camera at the two positions, and $\frac{1}{S}$ the scale of the drawing, we have

$$E = f\left(\frac{ac}{ac_1} - \frac{bc}{bc_2}\right) S$$

from which S may be determined, and then the actual distance between A and B as represented by *ab* scaled.

The maximum inclination allowable in the method just given is about 5°. If the angle of inclination exceeds 5° it will be necessary to employ the method described for case 1 (fig. 13). For rapid reconnaissances, therefore, it is essential that the angle of inclination of the negative be kept below 5°.

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 658

GEOLOGIC STRUCTURE IN THE CUSHING OIL AND GAS FIELD, OKLAHOMA

AND ITS RELATION TO THE OIL, GAS, AND WATER

BY

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Prepared in cooperation with the Bureau of Mines

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CONTENTS.

ILLUSTRATIONS.

These facts are published in the hope that they may be of use to the oil geologist and may show the "practical man" the value of geology in developing and operating an oil field. Not much more than the bare facts determined have been recorded, for until other fields have been similarly studied and more facts become available, only tentative theories can be advanced to account for the phenomena observed.

SUMMARY.

The geologic work done in the field has disclosed the following principal facts:

1. The folding of the formations in the Cushing field usually becomes greater with increase of depth, and there are many marked differences in structure among the Layton, Wheeler, and Bartlesville sands and the surface beds.
2. The interval between the Layton and Bartlesville sands is generally greater around the edges of the anticlines than on their crests.
3. The distribution of the bodies of oil, gas, and water indicates that the source of the oil lay west of the Cushing field.
4. In general the oil area in an elongated dome, where folding is simple, extends farther down on the long axes of the anticline or dome than on the steeper sides.
5. The water surfaces on which the oil and gas rest in the different sands are not level but are inclined away from the centers of the anticlinal folds.

ACKNOWLEDGMENTS.

In carrying on this investigation it has been necessary to obtain logs of wells and other statistics from the records of many of the companies operating in the Cushing field and nearly every operator has shown courtesy as well as willingness to assist in the investigation. Acknowledgments are especially due to the Gypsy Oil Co., the Carter Oil Co., the Southwest Oil Co., the McMan Oil Co., the Prairie Oil & Gas Co., the Slick Oil Co., B. B. Jones, and C. B. Shaffer. Mr. W. A. Williams, chief of the petroleum division, Bureau of Mines, under whose direction the work was done, and Mr. J. O. Lewis, of the Bureau of Mines, offered many valuable suggestions. Special thanks also are due to Mr. M. J. Munn, chief geologist of the Gypsy Oil Co., whose suggestions and advice have been invaluable, and to Mr. Max W. Ball, who carefully read the manuscript of the report. The figures giving the heights above sea level of the mouths of the wells—figures that made it possible to prepare the accompanying maps showing the underground structure of the oil sands—were in part furnished by the Gypsy and Carter oil companies; the remainder were taken by the writer with a plane-table in the spring of 1916.

VIEW WESTWARD ACROSS CIMARRON RIVER NEAR THE CREST OF THE DROPRIGHT DOME.

Drumright in the distance. Wheeler terrace on the left.

RIVER-BED LEASE ON WEST SIDE OF DROPRIGHT DOME.

DEVELOPMENT.

Although geologists who visited the western part of the Creek Nation in preceding years recognized the fact that the geologic structure in the Cushing field was favorable to the accumulation of oil, no oil was discovered there until March, 1912, when C. B. Shaffer and others drilled well No. 1 on the Annie Jones (F. M. Wheeler) farm, in the NW. ¼ sec. 31, T. 18 N., R. 7 E., about a mile north of the present site of Drumright. This well was drilled to the Wheeler sand, and for more than a year and a half this and the Layton sand produced the entire output of oil made by the field. In December, 1913, however, the Prairie Oil & Gas Co. completed the first well to the Bartlesville sand, in sec. 3, T. 17 N., R. 7 E.

The development has been extremely rapid, especially since the discovery of oil and gas in the Bartlesville sand—so rapid that it has resulted in great waste of oil and gas. The production of the field reached more than 300,000 barrels of oil a day, and at one time about 160,000 barrels of oil were being produced daily by 160 wells from the Bartlesville sand alone. The "break" in the market that followed this flood of oil and the inadequate transportation facilities made it necessary to store great quantities of oil on tank farms. The total marketed output of all the oil sands in the Cushing field to October 1, 1916, was about 165,000,000 barrels.

Figure 1 shows the development of the field by months since the first well was drilled to the Wheeler sand—from March, 1912, to September, 1916.

In view of the large number of producing sands the field is, on the whole, easy to operate. Drilling is rapid, the formations "stand up" well, the productive formations lie at moderate depths, and wells that produce an excellent quality of high-grade oil can be sunk at comparatively low cost.

The field has been well defined by dry holes, most of which have been drilled sufficiently deep to constitute a thorough test of its limits. The locations and depths of these dry holes are shown on Plate IV (in pocket). The field will probably not be extended far in any direction. The district southeast of Shamrock is not yet so completely drilled as the other parts of the field, but it is practically outlined. In less developed parts of the field the greatest new output will probably be derived from the more porous parts of the oil sands and from small anticlines or domes defined by geologists or drilled into accidentally. Another possible source of more production is the deeper formations. The Tucker sand has been thoroughly exploited, but what may lie below the "Mississippi lime"—the upper part of the Mississippian, a few hundred feet below the Bartlesville sand—is not yet disclosed, as no well that is known to the writer has

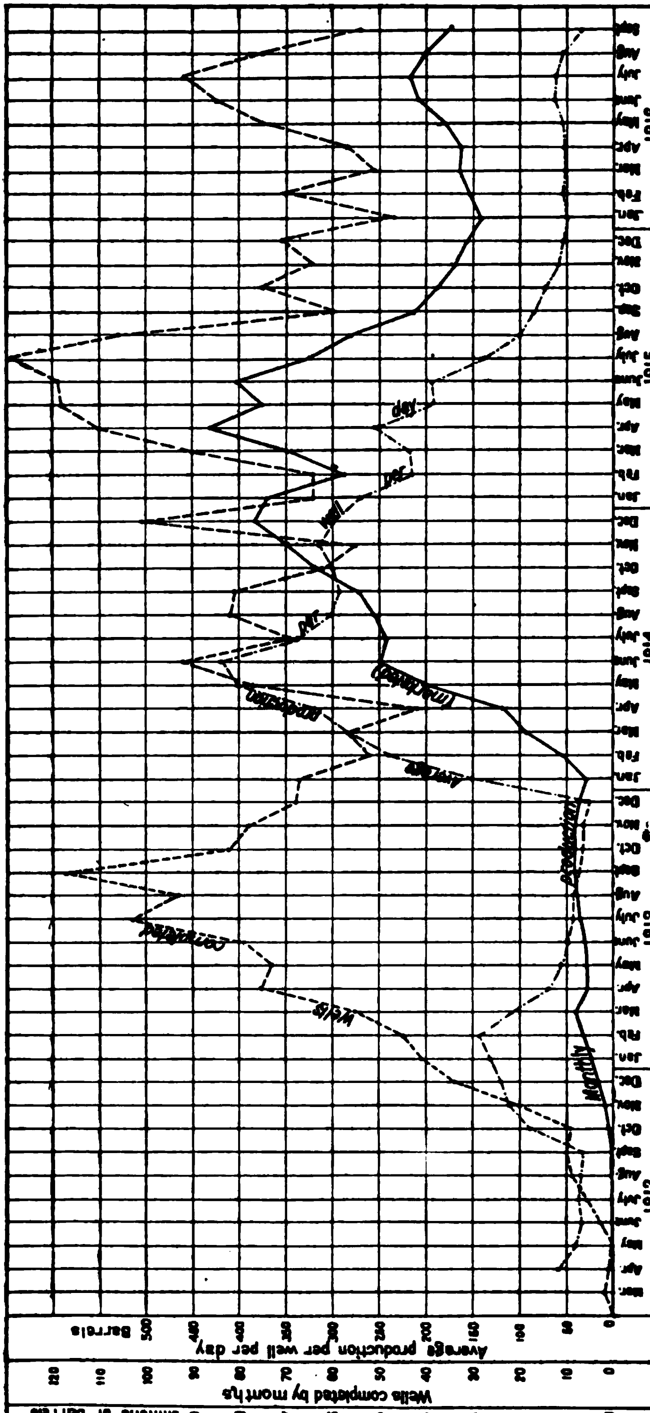


FIGURE 1.—Curves showing number of wells completed, by months, average daily production of oil per well, and quantity of oil marketed per month. Statistics obtained from Oil and Gas Journal.

penetrated the Mississippian in the Cushing field to a depth of more than 200 feet. Possibly more oil may be obtained on some of the folds of sands between the Tucker sand and the "Mississippi lime."

Much of the information in this report is derived from well logs. Detailed logs are scarce, for most operators in the Cushing field record only the depth and thickness of sands that may be productive. The water sands are omitted from many logs, and also the depth and thickness of members intervening between productive sands.

The incompleteness of these records seems to be due to the failure of the operators to realize the value of complete well logs, which should include not only a detailed list of the formations penetrated by the drill but measurements made by a steel line from the mouth of the well to the top of each productive sand. The log should show the character and content of each sand and the height to which water or oil rises in the well when the formations containing them are penetrated. The dates of completion, redrilling, deepening, and shooting, and all other information that may be of value should be recorded, for this record may greatly assist future operators of the property, especially when the field reaches the first stages of depletion and is being encroached upon by water.

STRATIGRAPHY.

ROCKS EXPOSED AT THE SURFACE.

This report does not include an account of the areal distribution of the formations or a detailed description of their features, for the surface geology of the district has not been studied extensively by the writer. Some of the statements here given regarding the surface rocks are in substance those made by Buttram,[1] of the Oklahoma Geological Survey.

The rocks of the Cushing field are exclusively sedimentary (see Pl. III) and, except the terrace sands and alluvial deposits, are all of late Pennsylvanian age. The Pennsylvanian rocks exposed at the surface lie near the top of that series. Between the western limit of the field and the upper or western limit of the Pennsylvanian series about 400 feet of strata crop out, including the Neva limestone and representatives of the Elmdale and underlying formations. In accordance with the provisional current usage of the United States Geological Survey, the line between the Pennsylvanian and Permian is drawn at the base of the Cottonwood limestone, which is about 50 feet above the Neva limestone. It should perhaps be drawn as low as the Neva limestone, or possibly at the base of the Elmdale, which embraces 130 feet of sediments below the Neva limestone of the Kansas section. This limestone forms an escarpment just west of the town of Cushing, Okla., and 12 miles west of the oil field.

[1] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, 1914.

The following table gives the geologic formations of the Pennsylvanian series as reported by Buttram in the vicinity of Cushing field—the oldest at the bottom and the youngest at the top:

Neva limestone.
Sandstones and shales and thin limestones (556.5 feet).
Pawhuska limestone (provisional correlation). Is 2,340 feet above Fort Scott limestone and 1,243 to 1,262 feet above Lost City limestone.
Shales and sandstones (134 feet).
Elgin sandstone.
Interval.
Lost City limestone.
Interval (1,078 to 1,097 feet). Includes Layton sand at 700 to 810 feet above Wheeler sand.
Fort Scott or Oswego limestones (75 feet) (=Wheeler sand).
Interval.
Bartlesville sand. (Belongs in Cherokee shale.)

According to Mr. Buttram, who has carried preliminary field work from the northern limit of the Cushing field northeastward toward the Cleveland oil field, the most prominent outcropping stratum is a bed of limestone that is in part at least equivalent to the Pawhuska limestone of northern Oklahoma, as described by Smith,[1] although careful and accurate correlation is yet to be made. Later investigations made by the United States Geological Survey in regions northeast of the Cushing field indicate a necessity for some nomenclatural revisions, which, however, are not yet completed. It is even somewhat probable that the limestone called by Buttram the Pawhuska and used in this report as a key horizon may not be the same as that which is conspicuously exposed near Pawhuska.

The rocks exposed at the surface within the Cushing field represent strata aggregating in thickness about 225 feet.

ROCKS PENETRATED BY THE DRILL.

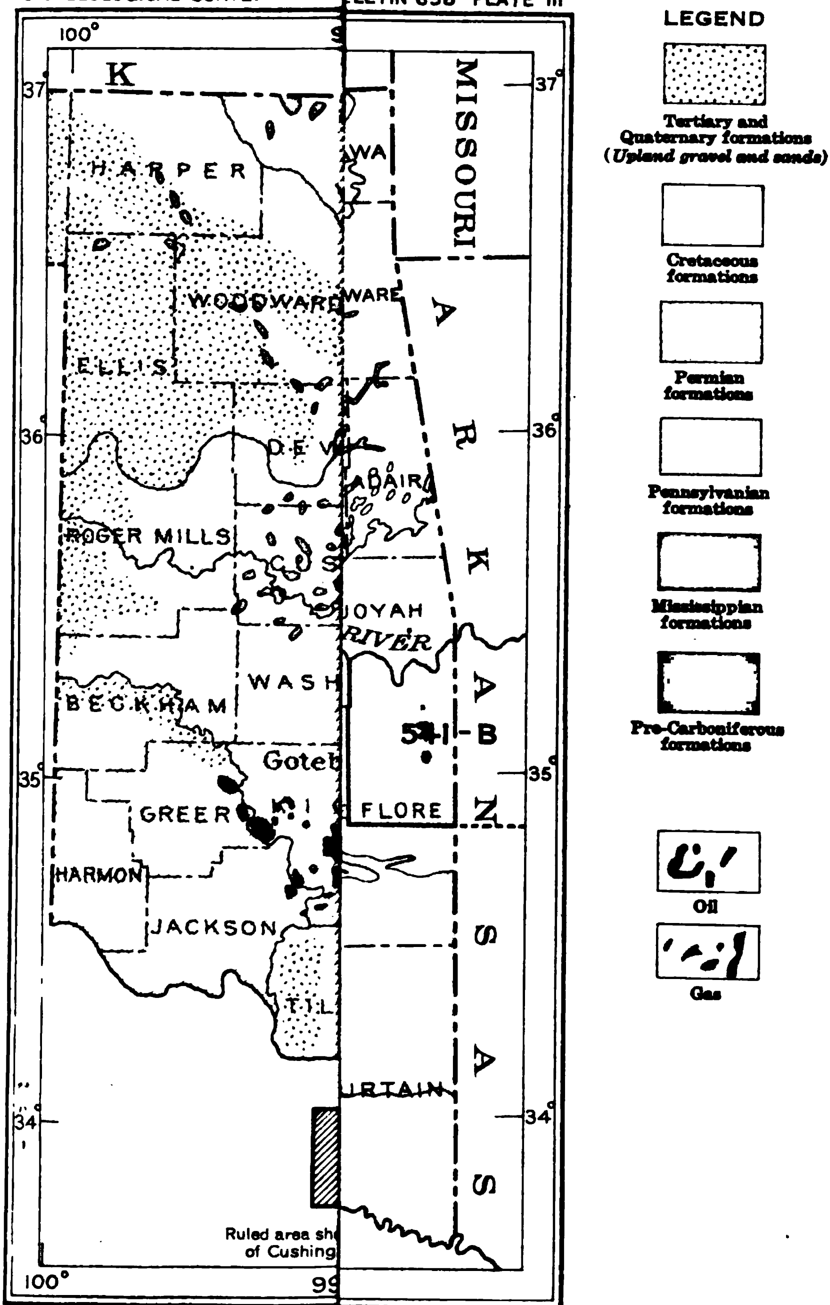
The drill penetrates a series of alternating sandstones, shales, and limestones, the limestones apparently becoming less prominent and the sandstones most prominent toward the south end of the field near Shamrock. According to Buttram the Pawhuska limestone near the center of the field, in the vicinity of Drumright, lies about 2,340 feet above the Wheeler sand, which is thought to be equivalent to the Fort Scott ("Oswego") limestone. The Bartlesville sand here is supposed to be equivalent to the Bartlesville sand of the fields of northeastern Oklahoma.[2]

The following are typical logs of the strata encountered in the northern part of T. 17 N., R. 7 E., in the central part of the field.

---

[1] Smith, J. P., The Arkansas coal measures in their relation to the Pacific Carboniferous province: Jour. Geology, vol. 11, p. 199, 1894.

[2] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, p. 43, 1914.


LEGEND
Tertiary and Quaternary formations (Upland gravel and sands)
Cretaceous formations
Permian formations
Pennsylvanian formations
Mississippian formations
Pre-Carboniferous formations
Oil
Gas
MISSOURI
ARKANSAS
HARPER
WOODWARD
ELLIS
ROGER MILLS
BECKHAM
WASH
GREER
HARMON
JACKSON
ADAIR
FLORE
RIVER
Goteb
100°
37°
36°
35°
34°
Ruled area sh
of Cushing

Record of well No. 24, sec. 8, T. 17 N., R. 7 E.

[Lessor, N. Yarhola.]

Record of strata.	Thickness.	Depth.
	Feet.	*Feet.*
Rock, red, soft	10	10
Sand, white, soft	50	60
Rock, red, soft	40	100
Sand, white, soft	50	150
Rock, red, soft	50	200
Sand, white, soft	15	215
Shale, blue, soft	35	250
Sand, white, soft	20	270
Rock, red, soft	80	350
Lime and sand, white, hard	25	375
Rock, red, soft	50	425
Sand, white, soft	25	450
Shale, white, soft	50	500
Sand, white, soft	60	560
Shale, white, soft	160	720
Sand, white, soft	70	790
Shale, blue, soft	140	930
Sand, white, soft	10	940
Shale, blue, soft	20	960
Lime, white, hard	10	970
Sand, white, soft	50	1,020
Shale, white, soft	40	1,060
Lime, white, hard	15	1,075
Shale, blue, soft	270	1,345
Lime, white, hard	5	1,350
Shale, white, soft	15	1,365
Sand, white, soft (Layton sand)	65	1,430
Shale, white, soft	210	1,640
Lime, white, hard	5	1,645
Sand, white, soft	40	1,685
Shale, white, soft	115	1,800
Sand, white, soft	40	1,840
Shale, white, soft	140	1,980
Sand, white, soft	40	2,020
Shale, white, soft	75	2,095
Shale, black, soft	17	2,112
Lime, white, hard	60	2,172
Shale, white, soft	38	2,210
Sand, white, soft (Wheeler sand)	30	2,240
Shale, white, soft	195	2,435
Lime, pink, hard	10	2,445
Sand, white, soft	23	2,465
Shale, white, soft	45	2,510
Shale, black, soft	15	2,525
Sand, white, soft	103	2,628
Shale and shells, soft	41	2,669
Lime, white, hard	103	2,672
Sand, white, soft (Bartlesville sand)	2	2,674

Record of well No. 1, sec. 10, T. 17 N., R. 7 E.

[Lessor, Sandy Fox.]

Record of strata.	Thickness.	Depth.
	Feet.	*Feet.*
Soil	2	2
Sandstone	38	40
Shale, blue	8	48
Sand; some water	14	62
Lime	6	68
Sand, soft	10	78
Shale, red	20	98
Lime	8	106
Shale, blue	30	136
Lime, hard	6	142
Shale, red and blue	33	175
Shale, gritty	40	215
Shale, blue	15	230
Shale, brown	30	260
Lime	10	270
Sand, water	25	295
Shale, white	25	320
Rock, red	40	360
Sand	15	375
Shale, white	15	390
Sand	20	410
Shale	99	509
Slate	21	530
Sand, water	15	545
Rock, red	5	550
Shale	40	590
Sand	15	605
Shale	24	629
Lime	2	631
Slate	19	650
Lime, sandy	10	660
Shale	34	694
Lime	2	696
Shale	5	701
Lime	3	704
Shale	6	710
"Blackjack"	10	720
Shale	20	740
Sand, water	18	758
Shale	27	785
Sand	10	795
Break	5	800
Water sand, sharp	15	815
Slate	10	825
White lime	5	830
Slate	5	835
Sand	5	840
Slate	20	860
Lime	15	875
Shale	5	880
Sand, water, etc	30	910
Break	5	915
Sand, hard	30	945
Shale, blue	105	1,050
Lime	5	1,055
Shale	25	1,080
Lime	5	1,085
Shale	39	1,124
Lime	7	1,131
Shale	10	1,141
Sand, hard	9	1,150
Water sand	20	1,170
Shale	20	1,190
Lime	18	1,208
Shale, blue	289	1,497
Lime	17	1,514
Shale	13	1,527
Layton sand (strong showing of oil; no water)	51	1,578
Slate	14	1,592
Shells	21	1,613
Sand	20	1,633
Slate	132	1,765
Jones sand (some gas)	38	1,803
Slate	32	1,835
Lime	5	1,840
Slate	5	1,845
Cleveland sand (750,000 cubic feet gas)	30	1,875
Slate	330	2,205
Gas sand (1,000,000 cubic feet gas)	18	2,223
Slate	9	2,332
Wheeler sand (30 barrels oil; some gas, no water)	46	2,378
Shells	10	2,388
Slate (bottom of hole)	24	2,412

THE PRODUCTIVE SANDS.

In the Cushing field oil is being produced from six different sands—the Layton, Jones, Wheeler, Skinner, Bartlesville, and Tucker sands. Figure 2 shows the vertical relation of these sands.

Layton sand.—The Layton sand is found at depths ranging from about 1,200 to more than 1,500 feet, the depth depending on the locality. It is productive of oil principally in the northern part of the Cushing field, in the district south and east of Drumright, and in an area a few miles south of Shamrock. Generally it underlies a hard limestone, 10 to 20 feet thick, called by the drillers the "Layton lime," in contrast to the Layton sand, which is a soft sandstone not fully saturated with oil. The top of the sand is at many places barren and the "pay" generally lies in streaks, a condition probably due to differences in porosity and to intraformational barriers caused by cross-bedding. The maximum thickness of the sand reported is about 100 feet, and the average of many reports is about 50 feet. At a few isolated points no Layton sand has been found. The sand is coarse grained, porous, and comparatively soft, and is fairly uniform in texture and porosity. In the Cushing field about 14 square miles of this sand produced oil and 12 square miles originally carried much gas. The oil obtained from the Layton sand is lighter than any other "Cushing crude," the Bartlesville ranking next and the Wheeler last. The gravity of these three ranges from 38° to 43° B.

Jones sand.—The Jones sand lies about 200 feet below the Layton sand and produces oil in commercial quantities only in a small area on the south side of the dome in the north part of the field, although it contains a little oil and gas at many other localities. The sand at a few places is as much as 50 feet thick, although its average thickness is less, nearly all the logs examined reporting a thickness ranging from 15 to 35 feet.

Cleveland sand.—About 100 feet below the Jones sand is the Cleveland sand, from which, so far as the writer knows, oil has never been produced in commercial quantities, although, like the Jones sand, it contains some oil and gas at many localities. The Cleveland sand is thinner than the Jones sand and is not reported in some logs. Its thickness ranges from a few feet to 30 feet.

Wheeler sand.—From 600 to 900 feet below the Layton sand is the next commercially productive formation, known as the Wheeler sand, named from the Wheeler farm, which is a short distance northeast of Drumright, where it was penetrated by the first well drilled in the Cushing field. This sand is one of the most uniform in the field in thickness. It includes the overlying "Wheeler lime,"

from which it is separated by a shale "break" ranging in thickness from 50 to about 100 feet. The lower sandy member is correlated by the drillers with the "Oswego lime" of northeastern Oklahoma and southeastern Kansas. It is a coarse-grained, brownish limestone that includes porous or sandy layers which contain the oil. The part below the shale "break" is more porous than the part above it and comprises about half the formation. At some places the limestone above the shale "break" carries gas in commercial quantities, and at others, on the sides of the folds, it carries water.

The shale "break" between the two members ranges in thickness from 5 to 25 feet. In the Cushing field about 11 square miles of the Wheeler sand produced oil, and about 21 square miles produced gas exclusively. The Wheeler sand, like the Layton and Bartlesville sands, is not completely saturated.

Skinner sand.—The Skinner sand lies 250 to 400 feet below the Wheeler sand and is locally utilized for oil in the northern part of the Cushing field and at a few places near the center of T. 17 N., R. 7 E., southeast of Drumright.

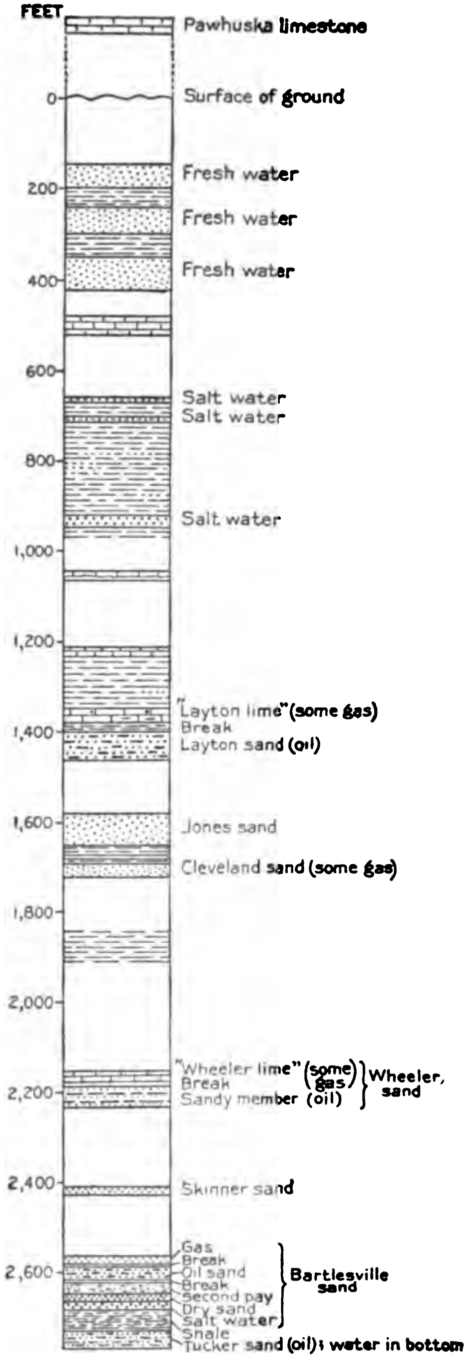


FIGURE 2.—Generalized columnar section showing the positions of the oil and gas sands.

Bartlesville sand.—From 350 to 550 feet below the Wheeler san lies the Bartlesville sand, the most productive oil sand in the Cus ing field. This "sand" ranges in thickness from a few inches about 200 feet, and in porosity from compact brown shale to len of porous brown coarse-grained sandstone. In different wells varies greatly in thickness, texture, and porosity and in its conte of oil, gas, or water. In some wells in the northern part of t field it attains a thickness of over 200 feet, and one part of the sa may be "dry," another part may carry great volumes of gas und tremendous pressure, still another part may furnish great quantiti of oil, and others may be filled with salt water. These so-call "streaks" are probably due to differences in porosity and appa ently occur in no regular order, salt water under great pressure b ing found in some wells above excellent oil "pay," below which mo water may be found, and below that more "pay." Notwithstandin these facts the sand has been immensely productive, though its yiel has not been so great as that which might be expected from a bod of sand so thick, for the real "pay" may form only a small pe centage of the total thickness of the sand. The total oil and ga area in the Bartlesville sand is about 20 square miles, of which but square miles carries gas only.

Tucker sand.—The Tucker sand lies from a few feet to about 20 feet below the Bartlesville sand, and is thought by some to be a par of that sand. The principal area in which oil is produced from th Tucker sand lies near Drumright and is not large. This sand is uniform in porosity, medium grained, and blue or bluish green, and although its average thickness is perhaps less than that of the Bartlesville, not enough wells have been drilled through it to determine this question. Many of the logs show that the Tucker sand is separated from the Bartlesville sand by a thin bed of green shale, which is recognized by the drillers as a "marker."

STRUCTURE.

DEFINITION OF GEOLOGIC STRUCTURE.

For the benefit of the reader who is not a student of geology, it may be stated that the term "geologic structure" means the form of the rock beds—the way in which they are folded or broken. Trough-like downfolds of the beds are called synclines; arches or upfolds are called anticlines or domes, the term used depending on their form. The angle between a sloping rock bed and a horizontal plane is called the angle of dip, and this angle may be expressed in degrees or in the number of vertical feet the bed slopes in a mile. A place at which the dip of the beds becomes more nearly flat is called a "terrace." An anticline may have high places or domes along its

axis, the axis being the line along which the beds are folded. The low place on the axis of the anticline between two domes or high places is called a "saddle."

VALUE OF A KNOWLEDGE OF GEOLOGIC STRUCTURE.

For various reasons, some of which are not yet thoroughly understood, oil ordinarily accumulates in the higher parts of anticlines and domes, and experience has taught oil men and geologists that synclines are more likely to contain salt water than oil. Thus the ultimate success of the operator in most of his test drillings depends on the form or structure of the beds beneath the place at which he drills, and he should therefore learn the location of the synclines and anticlines before drilling. The careful work of an experienced geologist is thus of great assistance to the operator, for if sufficient data are available the geologist is able to determine the structure of any region. No geologist can forecast with certainty in advance of drilling that oil or gas will be found at any particular place, but by careful work he is able to locate the places that are structurally the most favorable for the accumulation and the retention of oil and gas. The final and most important testimony is that recorded by the drill, and the claim by any one that he can certainly locate oil or gas should be looked upon with suspicion.

Although a capable geologist is of invaluable aid in selecting territory favorable for drilling, his work should not end after the first well is drilled, especially in a field as irregular as the Cushing, where the Bartlesville sand, the chief producer, is uneven in thickness, irregular in porosity, uncertain in minor structures and in rich "pays."

RELATION OF INITIAL PRODUCTION TO STRUCTURE.

The attitude or form of the beds of rock—the structure—is among the things first to be considered in drilling for oil, and one of the objects of this report is to show the practical man the value of drilling "on structure." The initial production of a large number of wells drilled to the three sands studied has accordingly been plotted, and lines have been drawn to outline the areas where the wells had certain initial production (Pls. VI–IX). Representative areas of each sand show that most of the places of greater initial production are on domes or anticlines or that they correspond in part at least to areas on the sides of the folds, where both oil and gas are found in the same sand. This fact is interesting, as many of the areas in the Layton and Wheeler sands that produce much oil occur down on the western side of the anticlines whose higher parts are completely

filled with gas (Pls. VII–IX). The prolific areas of Layton oil near Drumright and in the southern part of the field conform closely to areas wherein oil and gas occur together in the same sand (Pl. VII). On one side of the area of high-oil production, oil wells with smaller initial production are found without any marked amount of gas, whereas on the other side gas occurs without oil. The high initial productions from the Layton sand on the Dropright dome occur mainly on the north and northwest sides of the dome near the area where both oil and gas are found in the sand. The same relation is shown where oil and gas are found together in the Wheeler sand (Pl. VIII).

The areas of higher initial production of the Bartlesville sand east and southeast of Drumright are on the crests of nearly all the arches in that sand, where the oil and gas occur together (Pl. IX). The areas of large initial production in the Bartlesville sand on the Dropright dome coincide very closely with the structural crests and the initial production of areas outside the line inclosing wells with initial productions below 1,000 barrels a day drops off very rapidly on the flanks of the folds. In the area east of Drumright the line inclosing wells of initial production exceeding 3,000 barrels was not drawn, because not many wells that were so productive were found in this area. The line inclosing an area in which the initial production of wells is 1,000 barrels has been drawn, however, and this area incloses not only the dome that stands about 4 miles from Drumright but also the top of the flat anticline between this dome and the town of Drumright. These lines of initial production were not drawn in other parts of the field because of the lack of information and because they have not been considered necessary, for the map of the surface structure (Pl. V), which shows also the productive oil wells and the limits of production, indicates very exactly the intimate relation of production to geologic structure. If a geologist had entered this field prior to its development for the purpose of reporting on the probable value of the land for oil and gas, he probably would have chosen most of the territory now so thickly covered by oil wells as the productive part, for it conforms well with the upfolds of the outcropping beds, except, possibly, in the western part of the Wheeler terrace.

GRAPHIC METHOD OF REPRESENTING STRUCTURE.

The geologic structure or form of a rock bed can be best shown graphically by drawing a map bearing structure contours that represent lines of equal elevation of the bed. All points traversed by one of these lines are the same distance above or below sea level or some other chosen datum plane. For example, on a map where the contour interval is 25 feet, such as Plate V, all points on a certain

contour line are 900 feet above sea level, all points on the next higher contour line are 925 feet above sea level, all points on the third successive contour line are 950 feet above sea level, and so on. The interval between the lines—the contour interval—is thus 25 feet. The reader may obtain a fanciful conception of this device by imagining that all the formations have been removed above the bed contoured and that he is walking on this bed, keeping at all times a certain distance above sea level. The level course that he thus takes marks a contour, every point on which has the same elevation. The number of contours in a given space is thus determined by the steepness of dip. The contours thus drawn are of service in determining the places that are structurally favorable to the accumulation of oil and gas, because they show the location, size, and form of the arches and downfolds in the rocks, and anyone who has learned to read such structure maps is able to obtain at once a clear conception of the folding in the district which they represent.

In a region where the formations are deposited in nearly parallel layers the folds that occur in oil sands can be inferred from the folds that occur in the surface formations. The structure of some prominent rock bed on the surface that can be easily followed is approximately the same as the structure of the underlying beds, so that in order to determine the structure of an oil sand before any wells have been drilled the geologist first determines the structure of the surface beds. The structure of the surface beds may or may not be exactly the same as the structure of the oil sand, but in regions like the Mid-Continent field the two are in some degree concordant, so that a detailed map showing the structure of the surface beds is an excellent guide for prospectors. The value of a map of this sort may be seen by referring to Plate V, which shows the surface structure of this field as it was determined before much drilling was done and the limits of production of oil and gas.

The difference between contours drawn on the top of a rock bed that is here and there exposed at the surface and contours drawn on the surface of the ground itself should be clearly understood. The former show the form of the folded rock bed; the latter show the actual configuration of the earth's surface.

DETERMINATION OF THE STRUCTURE OF BEDS EXPOSED AT THE SURFACE.

The form or structure of a bed that is widely exposed at the surface in the Mid-Continent field is ordinarily determined by taking its elevation at many points where it is exposed. A persistent bed whose varying elevation is thus determined is called a "key bed," because it thus gives a key to the elevation of other beds that throughout the filed lie at nearly equal distances below or above it.

At some places this key bed dips below younger beds; at others it has been eroded away; and if the geologist wants to know the former elevation or the present elevation of this key bed at these places, he may learn it by determining the elevation of some other bed that throughout the field lies at a uniform distance above or below the key bed, and by deducting from or adding to the elevation of the bed observed the number of feet representing the interval between that bed and the key bed. In this way he reduces to figures applying to a single bed or stratum all elevations thus determined. After he has determined the elevation of a sufficient number of points on the key bed and plotted them on a map he can draw contour lines through points representing places of equal elevation above sea level, and thus prepare a map showing the form or structure of the bed plotted and by inference the form of other beds that lie at equal distances above or below it. By this method the surface of the Pawhuska limestone, which crops out over part of the Cushing field, as shown on Plate V (in pocket), was determined. The contours drawn on this bed represent vertical intervals of 25 feet, and each contour represents a continuous line having a certain elevation in feet above sea level—the elevation indicated by the figures marked on it.

DETERMINATION OF UNDERGROUND STRUCTURE.

The maps forming Plates VII, VIII, and IX (in pocket) show the folding—the form or structure—of the series of beds in the Cushing field. If there is no angular unconformity or thinning or thickening in the beds of the series the structure shown by these maps should be essentially like that of the surface bed. In preparing these maps the surface elevation and the logs of nearly all the wells in the Cushing field were obtained, and the elevation of each well was then subtracted from the depth of each sand given in the log of that well, the difference being the depth of the sand below sea level. After the elevations of the oil sands were plotted on a map, contours were drawn in the same way that they were drawn to determine the structure of the surface key bed. Obviously the accuracy of the structure contours on maps of this sort depends upon the accuracy of the logs and the well elevations, and inasmuch as a large number of the well elevations were obtained from different companies it is possible that they contain discrepancies and minor errors. Errors may also occur in the interpretation of the structure of a sand where it is discontinuous or where more than one interpretation of the data at hand is possible.

Contour maps of the principal producing sands in the Cushing field—the Layton, Wheeler, and Bartlesville sands—have been prepared. (See Pls. VII, VIII, and IX.) These maps show the struc-

ture of the sands, the distribution of oil and gas in each sand, the areas of higher initial productions, and the contours on the water surfaces in the three principal sands.

The structure map of the Layton sand was prepared by taking the drillers' measurements to the Layton sand and not those to the "Layton lime," which lies a few feet higher, but on the map showing the structure of the Wheeler sand the contours were drawn on the "Wheeler lime" and not on the lower sandy member, the term "Wheeler sand" as here used including the "lime" and the "sand."

Wherever the calculations made from the log of one well showed a marked change in structure that was not indicated in the logs of the neighboring wells, it has been assumed that the log or the well elevation is inaccurate, and the contours have been drawn as if the change indicated did not exist. If the logs of more than one well showed a change in structure, however, it was considered in drawing the contours.

STRUCTURE IN THE CUSHING FIELD.

GENERAL FEATURES.

The sediments that formed the rocks in the Cushing field are of Carboniferous age and were deposited in Pennsylvanian time. These sediments were laid down over a large area in almost horizontal layers that are now alternating beds of sandstone, shale, and limestone, some of which are carbonaceous and are supposed to have contained the material that formed most of the oil found in Oklahoma.

After the beds of the Pennsylvanian series were laid down, the Ozark Mountains in Arkansas, Missouri, and northeastern Oklahoma were formed by an uplift that gently folded the rock beds into arches and depressions, the general direction of the dip of the beds being away from the center of the uplift or, in general, toward the west or northwest. The uplift of the Wichita, Arbuckle, and Ouachita Mountains has doubtless influenced to a slight extent the folding of the rocks in this part of Oklahoma.

The dominant structural feature in the Cushing field is a broad north-south anticlinal fold along whose axis there are domes and along whose sides there are many subsidiary folds and irregularities. (See cross sections A-B and C-D, Pl. V, in pocket.) This great fold is one of the largest structural features in Oklahoma. The contours of the three oil sands are very irregular and differ locally from the contours of the surface rocks, although the general structure axes are practically identical. Each sand in the field exhibits small irregularities that apparently bear no definite vertical relations to each other; for example, the Bartlesville sand may have in it a small dome that has no counterpart in the Layton and Wheeler sands. On the other hand, one of the upper sands may have small structural features that do not occur in the lower sands. The differences may be due to

inaccuracy of the logs, as the drillers in some parts of the field have seldom made accurate measurements to any but the Bartlesville sand, or they may indicate actual irregularities in the structure of the sands, due to crumpling.

Not only do minor irregularities exist in the structure of the three sands, but at a few places the structure of one sand is radically different from that of the other two, although all may possess the same general structural features. In every part of the field the surface beds (Pl. V) are folded much less than any of the underground beds.

The large dome in the northern part of T. 18 N., R. 7 E., has already been called the Dropright dome,[1] and three other domes have also been named[2]—the Mount Pleasant dome, the crest of which is in the northeastern part of T. 17 N., R. 7 E.; the Drumright dome, which centers in sec. 33, T. 18 N., R. 7 E.; and the Shamrock dome, a large dome whose crest lies near the center of T. 17 N., R. 7 E.

Another dominant structural feature to which reference will often be made is the large saddle between the Drumright and Dropright domes, for which the name Wheeler saddle is proposed. The Wheeler sand has been extremely productive on rather a prominent terrace south of Drumright, and for this structural feature the name Wheeler terrace is suggested.

The saddle near the south edge of T. 17 N., R. 7 E., just south of the Shamrock dome, will be called in this bulletin the Shamrock saddle.

DROPRIGHT DOME.

Surface structure.—The Dropright dome (Pl. V) is one of the largest structural features in the Cushing field, occupying about 10 square miles.

The surface structure is simple. The crest of the dome lies on the east side of sec. 17 (Pl. III), and the formations dip in every direction away from the crest, but most steeply toward the east. Measurements made northeastward from the crest of the dome to a point less than a mile distant and from the crest of the dome to the bottom of the syncline, about 1½ miles distant, show dips of about 125 feet and over 175 feet, respectively. On the crest of the dome the "key bed," the Pawhuska limestone, which has been removed by erosion, would have an elevation of about 1,050 feet above sea level. From the crest an anticlinal axis extends a little east of north into the southern part of T. 19 N., R. 7 E. All sands in this anticline except the Wheeler have been extremely productive of oil. Another anticline extends northwestward from the crest of the dome

[1] Buttram, Frank, The Cushing oil and gas field, Okla.: Oklahoma Geol. Survey Bull. 18, p. 21, 1914.
[2] Idem, pp. 22, 23.

but plunges more abruptly and is broader and shorter than the one that extends northeastward.

Layton sand.—The highest contour on the Layton sand on the Dropright dome (see Pl. VII) is 400 feet below sea level. The crest of the dome is divided into two parts, one of which is in the NE. ¼ sec. 17, the other in the NW. ¼ sec. 16, T. 18 N., R. 7 E. From the latter the Layton sand dips steeply to the east, there being a difference of about 200 feet in its elevation within half a mile. In the Dropright dome the Layton sand has much stronger relief than the surface beds and a much steeper dip between the crest of the dome and the syncline on the east. The Dropright dome includes many subsidiary domes and many small "noses." Depressions in the Layton sand occur here and there on this dome, but the general structure is the same as that of the surface beds, and, of course, these minor irregularities may occur in the surface beds, though it was impossible to detect them.

Wheeler sand.—The structure of the Wheeler sand (Pl. VIII) on the Dropright dome is in general similar to that of the Layton sand, and the folding of the two is about the same, except that the east dip of the Wheeler is 100 feet greater in three-quarters of a mile than that of the Layton.

The top of the dome is broader and larger in the Wheeler sand than in either the Layton sand or the surface beds. The crest in the surface beds lies about a quarter of a mile southeast of the corresponding crest in the Layton sand. The dome is divided into two flat-topped parts, the eastern lying along the line between secs. 16 and 17, the western along the line between secs. 7 and 8. The crest of the higher or eastern part is less than 1,075 feet below sea level; that of the lower or western part is less than 1,125 feet below sea level. The western part has itself two crests, the southern standing just north of the common corner of secs. 7, 8, 17, and 18, the other about half a mile northeast of that corner. Lower down on the sides of the dome there are several other irregular domelike structures in the Wheeler sand.

Bartlesville sand.—The area of the dome in the Bartlesville sand (Pl. IX) is about the same as that in the Wheeler. In place of the two principal crests in the Wheeler sand there are three, all between 1,500 and 1,525 feet below sea level, arranged in a general northwest-southeast line and separated by depressions that extend northeastward. The southeastern crest is in the E. ½ sec. 17. It is slightly east of the eastern crest in the Wheeler and is much less pronounced. The middle crest lies in the SW. ¼ sec. 8, a quarter to a half mile west of the double-crested eastern dome in the Wheeler. The northwestern crest is on the line between the N. ½ secs. 7 and 8, half

a mile a little east of north of the northern crest of the western dome in the Wheeler. In the Bartlesville, as in the higher sands, there are structural "bumps" on the side of the general uplift, but they are smaller than the features already described. In the Dropright dome, though not elsewhere in the field, the Bartlesville sand, except at a few places, is less steeply folded than either the Layton or the Wheeler sand but is more steeply folded than the surface beds.

Elevation of sands.—The relations of the folds in these sands are shown in the following table:

Elevation in feet of highest contour on crests of four folds in the surface bed, the Layton sand, the Wheeler sand, and the Bartlesville sand, and the dip in different directions from the crests.

[+, above sea level; –, below sea level.]

	Dropright dome.				Shamrock dome.		
	Elevation of crest.	Amount of dip. 2½ miles northeast of crest along anticline.	Amount of dip. 1½ miles west of crest.	Amount of dip. ¾ mile east of crest.	Elevation of crest.	Amount of dip. 1½ miles west of crest.	Amount of dip. ¾ mile east of crest.
Surface beds	+1,050	100	150	125	+1,125	135	60
Layton sand	– 400	225	175	[a] 250	– 325	325	250
Wheeler sand	–1,075	225	200	[a] 350	–1,150	175	200
Bartlesville sand	–1,525	175	200	200	–1,550	325	250

	Mount Pleasant dome.					Anticline in northern part of T. 16 N., R. 7 E.	
	Elevation of crest.	Amount of dip. 2½ miles west of crest.	Amount of dip. 4 miles west of crest.	Amount of dip. ¾ mile southwest of crest.	Amount of dip. ¾ mile northeast of crest.	Elevation of crest.	Amount of dip ½ mile east of crest.
Surface beds	+1,100	150	225	75	75	+1,050	50
Layton sand	– 275	300	425	325	325	– 400	75
Wheeler sand	–1,100	350	475	325	400	–1,325	50
Bartlesville sand	–1,450	350	[b] 475	325	400	–1,700	100

[a] Part of vertical distance estimated.
[b] Part of horizontal and vertical distances estimated.

WHEELER SADDLE.

The Wheeler saddle lies between the Dropright and Drumright domes in the surface beds and is bounded on the northeast by a bowl-shaped structural depression over 30 feet in depth. Except for this depression the structure of the Layton and Wheeler sands is practically the same as that of the surface beds. The lowest point on the top of the Layton sand is about 575 feet below sea level. As the Bartlesville sand contains water on this saddle and as not many wells have been drilled to it, no map of that sand as it occurs in this saddle can be compiled.

DRUMRIGHT DOME AND NEAR-BY STRUCTURAL FEATURES.

Surface beds.—The Drumright dome (Pl. V), in the southern part of T. 18 N., R. 7 E., is separated from the Dropright dome by the Wheeler saddle and is a part of the general structural complex that includes the Mount Pleasant dome the crest of which lies about 2 miles to the southeast. In the surface beds this dome is by no means so well developed as the Dropright or the Mount Pleasant dome. Its highest contour stands 1,025 feet above sea level, and a saddle about 20 feet lower lies between this crest and the Mount Pleasant dome.

The surface beds in this part of the field dip gently to the west from the Mount Pleasant dome about 225 feet in 4 miles, but the normal western dip in the Layton, Wheeler, and Bartlesville sands is interrupted along a line extending southwestward through the Drumright dome, where these sands rise over an anticlinal fold. From the crest of this fold these three sands continue their westward slope, dipping 425, 475, and 475 feet, respectively, in a distance of 4 miles measured westward from the Mount Pleasant dome.

Layton sand.—On the fold extending southwestward from the Drumright dome the Layton sand (Pl. VII) is broad and very productive. It plunges southwestward for 2½ miles and dies out. Northwest of this fold and parallel with it is a much smaller fold which, plunging southwestward from the Drumright dome, passes through the town of Drumright and dies out near the west line of T. 17 N., R. 7 E.

Wheeler sand.—In the Wheeler sand (Pl. VIII) the larger fold does not plunge so far to the southwest as it does in the Layton sand but turns southward and connects in a broad, flat-topped anticline with the Shamrock dome.

Bartlesville sand.—The Bartlesville sand (Pl. IX) is folded much the same as the Wheeler, but the anticline that connects the plunging fold with the Shamrock dome is broader and is interrupted here and there by flat-topped domes. The Bartlesville and Tucker sands in these domes have been extremely productive.

MOUNT PLEASANT DOME.

Surface beds.—The Mount Pleasant dome (Pl. V) lies farther east than any other structure in the Cushing field and, with the exception of the Shamrock dome, stands the highest above sea level. The highest contour on the Mount Pleasant dome is 1,100 feet above sea level, or 50 feet higher than the highest contour on the Dropright dome and 75 feet higher than the highest on the Drumright dome.

The crests of the Mount Pleasant dome in the three different sands coincide very closely, but the surface beds form an anticlinal fold

that plunges rather steeply toward the southeast. About 1¼ miles northeast of the Mount Pleasant dome is a syncline into which the surface beds dip a vertical distance of 100 feet from the top of the dome. The dome is bounded on the south and southwest by another syncline, which is connected with the one on its northeast side. The beds on the south of the dome dip about 75 feet into this syncline. From the northern part of the dome the surface formations dip regularly to the west at the rate of 50 to 60 feet to the mile, except at a few places. There are very few surface indications of the irregularities in the underground structure that have been disclosed by the wells drilled.

The oil sands.—The structure of the Layton sand on the Mount Pleasant dome is somewhat like that of the surface beds, but the dip away from the crest is much steeper. About three-fourths of a mile southeast of the crest of the dome the Layton sand flattens out into a terrace and a small dome. This feature is repeated in the Wheeler sand, which is very similar in structure to the Layton sand, but the Bartlesville sand shows not only this subsidiary dome but another of about equal size, which lies near the center of the NE. ¼ sec. 11, T. 17 N., R. 7 E. (See table on p. 24.)

WHEELER TERRACE.

Except in an area near the west line of T. 17 N., R. 7 E., and a few small "noses" here and there, the Wheeler terrace is by no means so pronounced in the surface as in the underground beds. This surprising fact was brought out in the compilation of the underground-structure maps. It is evident that the surface-structure map of the area near Drumright shows few facts which would indicate that the Wheeler sand in that area would be as productive of oil as it has proved to be.

SHAMROCK DOME.

Surface beds.—Comparable in size to the Mount Pleasant dome is the structure called the Shamrock dome (Pl. V), which stands near the center of T. 17 N., R. 7 E., and is bounded on the east by a large syncline. The highest contour on the Pawhuska limestone on this dome is 1,125 feet above sea level, 25 feet higher than that on the Mount Pleasant dome, and is the highest in the Cushing field. The eastern dip between the crest of the dome and the syncline amounts to about 90 feet in 1½ miles. On the north the fold dwindles out into normal westward-dipping beds, but on the south it is drawn out in a long, plunging anticline, which begins to ascend as it crosses the township line between T. 16 N., R. 7 E., and T. 17 N., R. 7 E. The dip measured from the crest of the dome westward for about 2 miles amounts to 175 feet. In the next mile the dip flattens into the normal westerly dip of about 50 feet, or less, to the mile.

The oil sands.—The crests of the Shamrock dome in the Layton, Wheeler, and Bartlesville sands (Pls. VII, VIII, IX) are practically coincident and extend from north to south, but the crest of the surface structure appears to be about one-fourth of a mile farther west—an appearance that may represent the facts or that may be due to a slight error in the determination of the surface structure.

The folding of the formations in this dome, with the exception of the Wheeler sand, becomes greater with increase of depth. (See table on p. 24.) In a distance of 1½ miles west of the crest of the dome the Layton sand dips about 325 feet, the Wheeler 175 feet, and the Bartlesville 300 feet. The surface beds dip but 135 feet. The eastern dip in about three-fourths of a mile in the Layton is 250 feet, in the Wheeler 200 feet, and in the Bartlesville 250 feet.

OTHER STRUCTURAL FEATURES.

In the northern part of T. 16 N., R. 7 E., an anticline in the surface rocks extends northeastward across the township line just south of the Shamrock saddle, the highest part apparently being at the southwest corner of sec. 3. This anticline is a southern extension of the folding that resulted in the Shamrock dome, from which it is separated by the Shamrock saddle, the lowest part of which in the surface beds lies probably not more than 10 feet lower than the crest of this fold. From the crest of this fold the anticline plunges rather steeply southwestward for over 2 miles and finally dies out. The syncline on the east is a little over a mile distant, and the dip from the southwest corner of sec. 3 to this syncline amounts to about 120 feet.

Although the surface beds show that the highest part of this fold lies near the southwest corner of sec. 3, drilling has proved that the highest point in the three sands contoured is about a mile northeast of that point, although a sufficient number of deep wells have not yet been drilled west, east, and south of this fold to determine the exact differences in structure. The surface beds on the Shamrock saddle dip gently to the east and to the west from the top of the fold, but the structure of the Layton sand is in general that of a saddle but is much more irregular. A small dome occurs in the Wheeler and Bartlesville sands just east of Shamrock and on the west side of the Shamrock saddle.

Although there are faults in the Cushing field none have been drawn on the maps showing the structure of the oil sands or the surface beds, because the structure can be explained without assuming the existence of faults. A fault may exist on the Drumright dome in both the Layton and Bartlesville sands, and the northwestward-trending scarp on the north side of the Dropright dome in the Wheeler and Bartlesville sands may be due to faulting.

THE LAYTON-BARTLESVILLE INTERVAL.

ATTEMPT TO PREPARE A "CONVERGENCE MAP."

Geologic studies of the structure of some regions, especially a region where the rocks have low dips, show that the formations become thinner or thicker in certain directions. The structure of an oil sand is ascertained by determining the structure of a "key bed," as explained on pages 19–20, but if the thickness of the beds between the "key bed" and the oil-bearing sand varies from place to place it becomes necessary to map that variation before attempting to determine the structure of the oil-bearing beds. Therefore a "convergence map" is prepared on tracing cloth or paper by determining from available well logs the aggregate thickness of the formations between the "key bed" and the oil sand at a number of places in the area and by interpolating lines of equal interval, or "isochore" lines, to show how the beds converge and diverge. This tracing is then superposed on the map of the surface structure, and wherever the isochores cross the surface-structure contours the interval between the "key bed" and the oil sand at that point is deducted from the elevation of the "key bed" to obtain the elevation above or depth below sea level of the oil sand. After as many elevations as possible are obtained contours are drawn to show the structure of the sand.

In the present investigation the thickness of the formations between the Layton and Bartlesville sands was found to be exceedingly variable, and as the structure of the Layton sand was so different from that of the Bartlesville and showed even greater variations from that of the surface beds, it was decided to construct a "convergence map" to determine if possible whether there is a regular increase or decrease in the interval between the Layton and Bartlesville sands. This determination would be of service in ascertaining the structure of the Bartlesville sand over rather large areas in which wells had not been drilled deeper than the Layton or Wheeler horizons.

Figures showing the Layton-Bartlesville interval in all the wells from which data were available were accordingly calculated and plotted on a suitable map, but the results were so irregular that it was found impracticable to construct a "convergence map." As the information had been assembled, however, it was decided to separate from one another the areas where the intervals lay between certain limits and to record these on a map showing the structure of the Layton sand. (See Pl. X.)

One of the results of this study has been to show that the distance between the Layton and Bartlesville sands increases gradually from north to south. The smallest interval recorded in the logs is 945 feet and lies on the west side of the Dropright dome; the largest

interval is 1,366 feet, and lies about 12 miles southeast in the northern part of T. 16 N., R. 7 E. The gradations between these limits are very irregular and are indicated on the map in irregular areas, all wells showing an interval of less than 1,050 feet being separated from those in which the interval is between 1,050 and 1,100 feet, which in turn are separated from the areas where the interval is between 1,100 and 1,150 feet, and so on.

DISTRIBUTION OF THE INTERVALS.

The principal area that includes wells showing an interval of less than 1,050 feet lies on the crest and the west side of the Dropright dome, and a smaller area, in which the wells show the same interval, is found on the east side of that dome. A large, irregular area that includes wells showing an interval of 1,050 to 1,100 feet lies principally on the crest of the Dropright dome, but includes a few small patches in the same locality. Three other areas that show the same interval lie east and southeast of Drumright. Many irregular patches that show intervals between 1,100 and 1,150 feet are found in the northern part of the Cushing field, the largest occupying a part of the crest and the northern slope of the Dropright dome as well as a narrow band that extends down the east side of the dome and curves around to the south side, where it occupies the greater part of the Wheeler saddle. Wells that show this interval are found also in a large area southeast and east of Drumright, the southwestern extension of which lies at about the middle of sec. 17, T. 17 N., R. 7 E.

An area that shows intervals between 1,150 and 1,200 feet lies in the northern part of the field, mainly on the eastern side of the Dropright dome. The area curves around the south side of the dome, trends thence southward over the Wheeler saddle, and, except for a space near the township line in which information was insufficient to determine completely its limits, completely surrounds the areas of lesser intervals lying east and southeast of Drumright. In the NE. ¼ sec. 22, T. 17 N., R. 7 E., there is another area in which the interval is the same, and still another was determined from the logs of a few wells about 1½ miles east of Shamrock.

The areas in the northern part of the field that show intervals between 1,200 and 1,250 feet are small and are found in two patches on the east side of the Dropright dome, and in two other small patches on the south and southeast sides of that dome. Another small area in which the interval is the same lies southeast of Drumright, in sec. 8, T. 17 N., R. 7 E., but a larger one extends from sec. 1, T. 17 N., R. 7 E., southwestward to sec. 21, T. 17 N., R. 7 E., and is continued in a northward-trending band south and southeast of Shamrock.

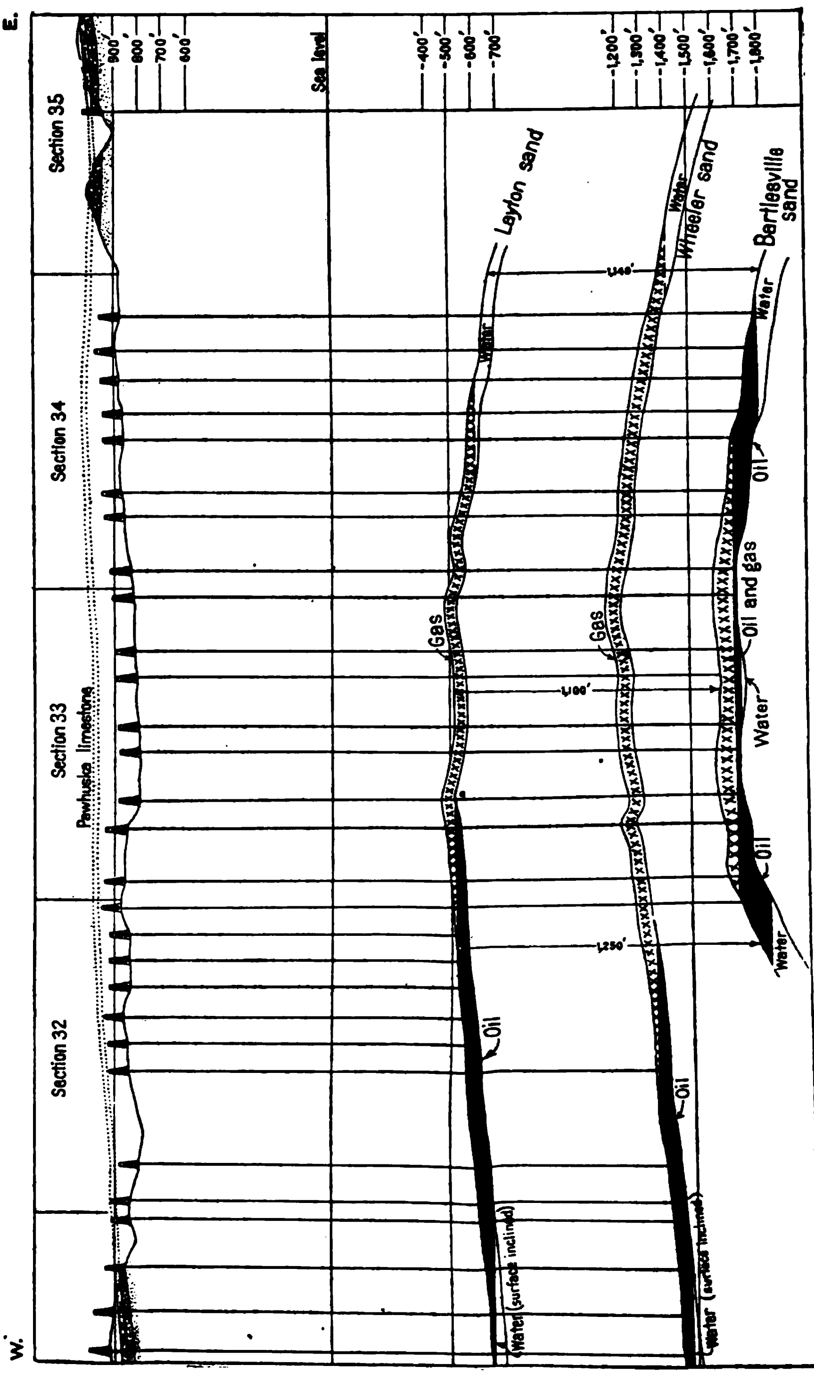


FIGURE 8.—Sketch section along south line of T. 18 N., R. 7 E., through the Drumright dome, showing the stratigraphic relations of the Pawhuska limestone and the Layton, Wheeler, and Bartlesville sands, the increase in the Layton-Bartlesville interval, and the inclination of the water surfaces.

The areas that show intervals of 1,250 to 1,300 feet are irregularly distributed from sec. 1, T. 17 N., R. 7 E., southwestward and southward to the vicinity of Shamrock, where they open out into a large area that extends southward nearly to the southernmost well drilled to the Bartlesville sand.

Most of the areas that show intervals of 1,300 feet and more lie south of Shamrock, but a few small areas are found in secs. 2 and 11, T. 17 N., R. 7 E.

RELATION OF INTERVALS TO STRUCTURE.

The map that forms Plate X shows not only that the interval between the Layton and Bartlesville sands is greater at the south end of the Cushing field but that a definite relation exists between the folds and the thickness of the beds in the interval, for the interval is generally less on the crests of the folds. For example, the interval between 1,050 and 1,100 feet lies on the crest of the Drumright dome (fig. 3), on the broad, flat-topped fold in the Bartlesville sand about 2 miles south of that dome, and on the Mount Pleasant dome. These areas are completely surrounded by areas showing an interval between 1,100 and 1,150 feet, which in turn are nearly surrounded by areas that show greater intervals and that lie farther down on the folds. The same relation is shown by the Shamrock dome, where areas that represent intervals between 1,150 and 1,200 feet lie on the crest and are completely surrounded by areas representing greater intervals. On the Dropright dome the relation is not so decidedly shown, though it evidently exists on the east and south sides.

POSSIBLE CAUSES OF DIFFERENCES IN FOLDING.

ITEMS CONSIDERED.

The relations indicated would naturally be expected if the Bartlesville sand is more steeply folded than the Layton sand, and to explain the difference in interval with relation to structure we must look to the causes of the difference in folding. It must not be thought, however, that the general increase from north to south in the Layton-Bartlesville interval can be attributed to differences in folding. This increase is undoubtedly due to the conditions under which the formations between the Layton and Bartlesville sands were deposited.

The differences in the folding may possibly be due to any one or a combination of two or more of the causes enumerated below.

1. The difference in resistance to compression of the hard and soft beds of which the formations in the Cushing fields are composed.

2. The lenticular form of the Bartlesville sand.

3. One or more unconformities between the surface beds and the Bartlesville sand.
4. Folding during deposition.
5. Cross folding.

DIFFERENCE OF HARD AND SOFT BEDS IN RESISTANCE TO COMPRESSION.

Although the difference of the hard and soft beds in resistance to compression might account for some of the difference in folding in a region of gentle folding like this, it seems unreasonable to attribute to this cause an increase of 325 feet in thickness in a horizontal distance of a little over three-fourths mile, such as exists in secs. 2 and 3, T. 17 N., R. 7 E. Here the Layton dips 325 feet, the Wheeler 400 feet, and the Bartlesville 400 feet in that distance, whereas the surface beds have a dip of but 75 feet.

LENTICULAR FORM OF THE BARTLESVILLE SAND.

It has been suggested that the Bartlesville sand may not be actually folded more than the other sands above it, but that the difference in interval is due to the thinning out of the Bartlesville sand around the edges of the anticlines and domes. At many places around the edges of the pools the Bartlesville sand "pinches out," and throughout the field it is very irregular in thickness. In a well on the east side of the Dropright dome, in sec. 9, the Bartlesville sand is missing, and in sec. 4 the sand is "broken"—that is, it is full of streaks of shale. On the west side of the same dome the sand "pinches out," and on the southwest side it is much thinner than it is nearer the top of the dome. In sec. 28, T. 18 N., R. 7 E., it again thins out, and in the logs of several wells in sec. 33 it has been described as "dry" and "broken." The sand thins rapidly as it approaches the "water line" in the area south of Drumright. On the northeast side of the Mount Pleasant dome, in secs. 2 and 3, T. 17 N., R. 7 E., the sand again "pinches out" and is only 8 feet thick in one well in sec. 12. On the south, east, and west sides of the Shamrock dome the sand is either lacking or is thin and broken, and it becomes much thinner in the extreme southwestern end of the field, in sec. 8, T. 16 N., R. 7 E., and on both the southeast and northwest sides of the anticline in the northern part of T. 16 N., R. 7 E.

It thus appears that the Bartlesville sand at many places thins out toward the edges of the pool, but whether this thinning causes the apparent differences in folding depends upon the conditions under which the sand was deposited. If it was deposited in the form of a lens on an apparently flat surface, the differences in the interval at places where the sand "pinches out" or thins perceptibly might be attributed partly to this fact, because the thickness of the sand

is at many places 150 to 200 feet. On the other hand, if all the difference in the interval is due to the lenticular form of the Bartlesville sand, it would naturally be supposed that measurements from the Wheeler sand to the Bartlesville sand at many localities would show the increase in interval as well as measurements from the Layton to the Bartlesville sand, or, in other words, that the interval between the Layton and Wheeler sands would remain constant. The Layton-Wheeler interval, however, like the Layton-Bartlesville interval, is greater around the edges of the domes and anticlines, a fact that can not be attributed to the "pinching out" of either sand, for the two sands are comparatively uniform in thickness throughout the Cushing field. The lenticular form of the Bartlesville sand is probably, therefore, only a secondary cause of the observed differences in the folding and in the interval in the Cushing field. The local conditions when this part of the Pennsylvanian series was deposited were certainly complex, and it would be difficult to determine just what effect the lenticular form of the sand has had on the interval and on the apparent discrepancy from place to place in the folding. Under some conditions of deposition it might have the effect of adding to the interval, under others it might have the effect of subtracting from it, but under still other conditions no effect whatever.

UNCONFORMITIES.

The lack of detailed logs of wells in this field has made it impossible to construct cross sections to show the exact relations of the formations that lie between the Layton and Bartlesville sands, and it is therefore impossible to state positively whether or not there are unconformities in these beds. If an unconformity should exist and the beds were folded before and after the break in sedimentation the difference in folding, so far as the Layton and Bartlesville sands are concerned, would be accounted for, but the difference in folding between the surface beds and the Layton sand is usually greater than that between the Layton and the Bartlesville sands (see table, p. 24), and although more than one unconformity may exist in the series between the surface beds and the Bartlesville sand, this alone can hardly have caused the differences in the folding and the interval.

FOLDING DURING DEPOSITION.

Were it not for the fact that in some parts of the field the Bartlesville sand is not folded so strongly as the upper formations, the differences in folding might seem to be due to folding along lines of weakness during the deposition of the beds, but if folding proceeded continuously during deposition, the Bartlesville sand would everywhere be folded more steeply than the other beds. But

this is not true. (See table, p. 24.) In comparatively sharp folds the intervals shown between two beds by drilled wells are greater where the beds are penetrated on the slopes of the folds, but the folds in the Cushing field are gentle, and the Layton-Bartlesville interval would appear to be increased only a few feet in records of wells drilled on the beds that have the steepest dip.

CROSS FOLDING.

Many of the differences in folding may be due to cross folding. The regional forces that produced the larger features of the structure in the Cushing field acted from the east, for the axis of the general uplift extends northward. Among the most striking features of the structure of the three oil sands are the systems of local cross folds which have two general trends—one about N. 40°–55° W. and the other about N. 35°–40° E.

One of the principal cross folds, which trends about N. 50° W., extends through the Mount Pleasant and Drumright domes. This fold is very evident in all the underground sands and also in the surface beds. (See Pls. V, VII, VIII, and IX.) The Dropright dome has been deformed by another parallel cross fold, which extends through its crest and forms a northwestward-plunging anticline in the surface beds and in the three underground sands.

Another cross fold extends in practically the same direction through the Shamrock dome. This fold is not so pronounced in the surface beds and in the Layton sand as it is in the Wheeler and Bartlesville sands.

Another system of parallel cross folds extends about N. 35°–40° E. One of these folds is in the northern part of T. 16 N., R. 7 E., and is rather pronounced in all the sands contoured, although the Wheeler and Bartlesville sands show it more plainly.

Another line of cross folding, not quite so prominent, is in the Layton, Wheeler, and Bartlesville sands and extends about N. 40° E. through the Mount Pleasant dome. On this cross fold lie the crest of the Mount Pleasant dome and the high place on the large flat-topped area just northwest of the Shamrock dome.

Still another line of cross folding parallels this, extending about N. 35° E. through the Drumright dome. This fold is very prominent and prolonged in the Layton and Bartlesville sands, though its southwestward extension is not so plainly shown in the Wheeler sand.

A less prominent line of folding occurs in the Layton sand about a mile northwest of that just described and extends in the same direction through the Wheeler terrace and the southern part of the Wheeler saddle. The well records now available do not show that this small fold occurs in the Wheeler or Bartlesville sands.

As the differences in folding can not reasonably be attributed solely to any one of the other causes stated, it is probable that they may have been produced by a combination of cross folding and the difference in resistance to compression of hard and soft beds.

RELATION OF OIL AND GAS TO STRUCTURE.

METHOD OF MAPPING.

The map represents the structure of the surface beds (Pl. V), and the cross sections A–B and C–D on that map show how the surface beds are folded. This map was constructed from elevations taken on top of the Pawhuska limestone or on some other bed a known distance above or below it, in the way that any surface-structure map is made before drilling has been done. The red line on the map incloses wells in which oil or gas has been found in any sand and shows that most of the productive areas conform to the arches and terraces in the rocks.

Plates VII, VIII, and IX (in pocket) show the areas of oil and gas in the Layton, Wheeler, and Bartlesville sands, respectively. These areas were determined by examining all the logs collected and by plotting from them on a map the contents of each sand encountered in each well. In some localities of minor commercial importance the areas determined may be wrong because some of the logs were incomplete and others were not available, but the map shows in general the shape and position of each area. The areas overlap in each sand and have narrow irregular strips in common, where both oil and gas were originally found in each sand. These strips separate the strictly oil areas from the strictly gas areas.

LAYTON SAND.

Gas occurs in the Layton sand (see Pl. IX) in an area that covers practically all the top of the Dropright dome. On the Wheeler saddle the Layton sand does not carry gas exclusively, but farther south, on the crest and eastern side of the Drumright dome, the sand is filled with gas. The western margin of this gas area extends southwestward roughly along the crest of the plunging anticline that terminates in sec. 8, T. 17 N., R. 7 E. The western boundary of the Layton gas then bears southeastward to sec. 16, and thence southward along the western flank of the Shamrock dome, the Shamrock saddle, and the anticlinal fold in the northern part of T. 16 N., R. 7 E. Practically all the Layton sand east of this line, including the Mount Pleasant dome, the Shamrock dome, the Shamrock saddle, and the anticlinal fold in the northern part of T. 16 N., R. 7 E., is filled with gas as far east as the water line.

The area in which both oil and gas are found on the Dropright dome forms a roughly circular strip around the sides of the dome, and the area that contains oil alone continues outward from this strip in all directions to the water level. The bulk of the oil produced from the Layton sand on this dome is derived from its north and northwest sides, but the oil extends on southward over the Wheeler saddle and joins the productive area on the Wheeler terrace in the northern part of T. 17 N., R. 7 E. In the Layton sand on the west slopes of the Shamrock dome and the fold in the northern part of T. 16 N., R. 7 E., oil is found in a narrow strip that extends southward and widens toward the southern end of the field into a highly productive pool.

A little oil has been found in the Layton sand on the east side of folds in T. 17 N., R. 7 E., and T. 16 N., R. 7 E., but only three small areas have thus far been commercially productive. One of these areas lies just south of the Mount Pleasant dome, another on the eastern flank of the Shamrock dome, and the third about a mile east of the crest of the fold in T. 16 N., R. 7 E. The initial production of wells drilled in these areas is low, and the total production of the wells in them is small as compared with that of the wells that tap the Layton sand on the west side of the field, in T. 17 N., R. 7 E., and T. 16 N., R. 7 E.

The lowest level at which gas alone was found in the Layton sand on the west side of the Dropright dome is about 525 feet below sea level, whereas the lowest corresponding level at places on the east side of the dome is about 550 feet below sea level. Much of the lowest gas on the east side is found as high as 450 feet below sea level.

On the west side of the field, on the Wheeler terrace, in T. 17 N., R. 7 E., the depth of the lowest gas ranges from about 500 to 550 feet below sea level, and on the west side of the Shamrock dome, the Shamrock saddle, and the fold in the northern part of T. 16 N., R. 7 E., the lowest gas remains fairly constant at a depth of 475 feet below sea level. On the east side of the field, in T. 17 N., R. 7 E., and T. 16 N., R. 7 E., however, the gas nearly everywhere rests on water, the surface of which ranges in depth from about 475 feet to 550 feet below sea level. The lowest oil on the west slope of the Dropright dome is about 575 feet below sea level, but the lowest oil on the north and northwest slopes is 650 feet below sea level. The lowest oil on the west side of the Wheeler saddle is nearly 650 feet below sea level, and the lowest on the east side is about 600 feet below sea level. The lowest oil obtained in commercial quantities on the Wheeler terrace lies 600 to 650 feet below sea level, and the highest oil on that terrace lies near the crest of the Drumright dome about 475 feet below sea level. The lowest oil on the west slope of the Shamrock dome lies about 600 feet below sea level and maintains

this elevation to the southern extension of the field, where the lowest oil lies from 550 to 575 feet below sea level.

The map (Pl. VII) shows that the distribution of the oil, gas, and water on the Dropright dome is in accordance with the anticlinal theory of oil accumulation as it was originally formulated, for gas occupies the crest of the dome, oil the flanks, and water lies below the oil. The arrangement of oil, gas, and water in the remainder of the field is different, as a great body of gas extends from the east side of the field, where it rests directly on water, westward over the crests of the folds to a line of uncertain elevation, where oil is encountered. From this line westward oil is found to the plane where "edge water" occupies the sand. Figure 3 (p. 30) shows this relation.

WHEELER SAND.

In the Wheeler sand (see Pl. VIII) on the Dropright dome gas is found almost exclusively, except in a small area about a mile southwest of Oilton, where some oil has been obtained from the Wheeler sand. The Wheeler gas extends southward across the Wheeler saddle and occupies all the Wheeler sand that lies between the eastern water level and a point just east of Drumright. The western boundary of Wheeler gas extends southward from the vicinity of Drumright for about 2½ miles and thence turns southeastward toward the Shamrock saddle. Most of the Wheeler sand on the Shamrock dome and saddle and on the dome in the northern part of T. 16 N., R. 7 E., is filled with gas even to the eastern water line, no oil intervening.

The small area of Wheeler oil production about a mile southwest of Oilton has already been mentioned. The principal area of Wheeler oil begins on the extreme southwest side of the Dropright dome and extends in a narrow band southeastward around the southern end of the dome and widens out to a large broad band that occupies a part of the crest and much of the western flank of the Wheeler saddle. At the township line near Drumright the band of Wheeler oil is over a mile wide, and north of Drumright where it occupies the Wheeler terrace it becomes still wider. Another area of oil production from the Wheeler sand comprises less than half a square mile at the head of a syncline between the Mount Pleasant and the Shamrock domes. Still another area, a little larger, begins about a mile north of Shamrock and extends southward through the town, occupying also a part of the west slope of the dome in the north part of T. 16 N., R. 7 E. This area has not yet been drilled for oil, which may not occur there in commercial quantities.

Wherever gas lies above oil in the Wheeler sand, the plane separating them is between 1,300 and 1,350 feet below sea level. The lowest gas on the eastern side of the field lies at depths ranging from

1,300 to 1,400 feet below sea level. On the west side of the Wheeler saddle, the oil lies as far down as 1,425 feet below sea level, but on the Wheeler terrace the oil is as far down as 1,475 feet below sea level. The lowest oil found west of the anticline in the northern part of T. 16 N., R. 7 E., is about 1,450 feet below sea level.

BARTLESVILLE SAND.

The Bartlesville sand (see Pl. IX) varies to a greater extent in thickness than either the Layton or Wheeler sand, and contains many strata of different textures and porosities. The coarse sandstone layers are interlaminated with the fine sandstone layers, and the whole Bartlesville sand is often divided vertically into many parts by thin shale layers called "breaks." These breaks may be so thin as to be unnoticeable to the drillers, but they are nevertheless adequate in thickness to form an effective barrier between the porous layers. Some of the porous streaks in the sand contain tremendous quantities of oil and are designated "pay streaks" or "pays." The volume and pressure of the gas in this sand were great on the crest of the Dropright dome—so great as to interfere seriously with the drilling of wells that were being deepened to oil. Some of the gas had a pressure of over 1,000 pounds per square inch and an open-flow volume of more than 50,000,000 cubic feet per 24 hours. The volume of gas decreased on the slopes of the dome and only small oil wells were obtained near the edges of the productive area. The Bartlesville gas does not extend over the saddle south of the Dropright dome, but it occurs with oil on the crest and east side of the Drumright dome, on the Mount Pleasant dome, and in a large area that extends from the Shamrock dome northwestward along the higher parts of the beds—an area in which it apparently overlies the oil. This area lies on the eastern side of the principal oil area. On the south and southeast sides of the Shamrock dome gas under heavy pressure occurs in the Bartlesville sand above the oil, but on the west side of the dome less gas and more oil are found. On the crest and the east side of the anticline in the northern part of T. 16 N., R. 7 E., gas alone occurs in the Bartlesville sand, and open-flow measurements made there run as high as 60,000,000 cubic feet daily and the rock pressure is over 1,000 pounds to the square inch. Large quantities of oil are found on the west side of this anticline.

On the north side of the Dropright dome the oil in the Bartlesville sand extends down to about 1,800 feet below sea level, but on the west side of the dome the plane between the oil and water is 200 feet higher. The same plane on the east side of the dome ranges from 1,650 to 1,800 feet below sea level.

On the sides of the Mount Pleasant dome the Bartlesville oil extends to depths of 1,650 to 1,750 feet below sea level, but on the

west side of the field, in T. 17 N., R. 7 E., and T. 16 N., R. 7 E., the oil becomes progressively lower from 1,750 feet near Drumright to 1,850 feet at the south end of the field. On the east side of the field, in the northern part of T. 16 N., R. 7 E., Bartlesville gas under heavy pressure extends down to 1,775 feet below sea level.

TUCKER SAND.

Although the areas of oil in the Tucker sand are of great commercial importance, they are so small as to be of very little value in the present study. Oil has been obtained in commercial quantities from this sand in a few wells in T. 18 N., R. 7 E., but the largest development is in T. 17 N., R. 7 E., not far from Drumright, where, in an area of about a square mile, wells derive oil from this sand on the fold extending southwest from the Drumright dome.

In February, 1916, the Gypsy Oil Co. completed a well to the Tucker sand in sec. 5, T. 17 N., R. 7 E., which had a reported initial daily production of 14,000 barrels of oil, and as a result of the success of this well many other wells have been drilled to the Tucker sand and many wells that had reached the Bartlesville sand have been deepened. A few wells on the Shamrock dome, a few in sec. 16, T. 17 N., R. 7 E., and about half of those on the Mount Pleasant dome have been deepened to the Tucker sand with successful results.

The Tucker sand yields oil only on the crests of the larger folds, in areas that are smaller in the aggregate than those which contain wells that reach any of the other sands because the sand is much more sharply folded. Gas under high pressure has been found in large quantities in the Tucker sand by a few wells drilled on or near the crest of the anticline in the northern part of T. 16 N., R. 7 E.

OCCURRENCE OF WATER.

Water is found in all the sands in nearly every well that has been drilled at points low down on the anticlines around the edges of the field except in a few wells sunk to the Wheeler and Layton sands on the west side of the Dropright dome and on the southeastern part of the Mount Pleasant dome, which have been reported dry. It seems rather peculiar that in these places the sands should be dry, but it is probable that the sands in such places are "tight." Water would not be noticed in a close or "tight" sand by drillers, even if it were present, whereas in the same horizon not far distant water would be noticed because the sands are less cemented.

PECULIARITIES IN DISTRIBUTION OF OIL AND GAS.

In a field where the sands were uniformly porous and the conditions of folding and of accumulation were uniform one would think that the line which separates the oil or gas areas from the water areas

would follow a structure contour, but in the Cushing field this is not true, for in some places the areas that contain only water lie much higher structurally than in other places, a fact shown on Plates VII, VIII, and IX by the line dividing the areas that contain oil or gas from those that contain only water.

The evidence indicates that in general the oil and gas areas in an elongated dome, where folding is simple, extend farther down on the long axis of the anticline or dome than on the steeper sides. In other words, the area that contains water only occurs at a higher structural position on the steeper sides of an elongated dome than it does on its plunging axis. This fact is shown particularly well in the Layton sand on the Dropright dome; on the west side the water completely occupies the sand at a depth of 500 feet below sea level, whereas on the north side the oil extends down as far as 650 feet below sea level and also completely occupies the Wheeler saddle on the south side of the Dropright dome. The lowest point on the Layton sand in the Wheeler saddle is about 575 feet below sea level, and oil extends down on the sides of the saddle to 650 feet below sea level on the west and 625 feet on the east.

The same condition is fairly well shown in the Layton sand on the Mount Pleasant dome, although this contains principally gas; on the steep southwest side of the dome the water completely occupies the sand at one place as high as 400 feet below sea level, and on the northeast side the water lies about 500 feet below sea level; whereas on the southeastward-plunging axis of this dome the lowest oil lies about 550 feet below sea level. On the east side of the Shamrock dome the gas extends down to about 500 feet below sea level. On the north side of the same dome the lowest gas is found resting on water at 425 feet below sea level, but this figure may be inaccurate, as very few wells have been drilled in that vicinity. South of the Shamrock dome the Shamrock saddle is completely filled with oil and gas, although its lowest point is about 475 feet below sea level. The gas extends down on the east side of the anticline in the northern part of T. 16 N., R. 7 E., where the lowest oil and gas are about 500 feet below sea level, but on the southwest extension of this plunging anticline the lowest oil is about 575 feet below sea level.

Practically the same conditions were observed in the Wheeler sand on the Dropright dome, where the lowest oil on the north side of the dome lies about 1,375 feet below sea level; the highest water on the west side is between 1,275 and 1,300 feet below sea level, and on the east side it ranges from 1,300 to 1,400 feet below sea level. The Wheeler saddle is filled with gas and oil in the Wheeler sand. The highest point on the saddle lies between 1,325 and 1,350 feet below sea level, and the oil is found as far down on the west side of the saddle as 1,400 feet below sea level. Similar conditions exist on

the Mount Pleasant dome, where the lowest gas on the southwest and northeast sides is about 75 feet higher structurally than the lowest gas on the southeastward-plunging axis.

This feature is plainly shown on the east side of the Shamrock dome, where the lowest gas rests on water at about 1,250 feet below sea level and the line separating the gas from the water extends southward, cutting across the structure contours to a point on the Shamrock saddle where the lowest gas lies 1,325 feet below sea level.

The same condition was observed in the Bartlesville sand on the Mount Pleasant and Dropright domes. The occurrence of this condition in the Bartlesville sand on the Dropright dome is especially interesting because the Bartlesville sand on the Wheeler saddle is completely filled with water, and no accumulation of oil and gas on the Wheeler saddle modifies the shape of the oil and gas area in the Dropright dome. The lowest oil on the more gently dipping south side of the Dropright dome lies 1,725 feet below sea level. On the north side the lowest oil lies about 1,800 feet below sea level, whereas on the eastern and western sides, where the dips are steeper, the lowest oil lies about 1,650 feet and 1,600 feet below sea level, respectively. The lowest oil in the Bartlesville sand on the steep southwest side of the Mount Pleasant dome is 1,700 feet below sea level; that on the northeast side of the dome ranges in depth from 1,675 to 1,750 feet below sea level. On the southeastern axis of the dome the lowest oil lies between 1,775 and 1,800 feet below sea level. The axis of the Mount Pleasant dome rises over the Drumright dome on the northwest, the lowest point on the axis between the two domes lying from 1,600 to 1,625 feet below sea level. The sands along this axis are completely filled with oil and gas. In the northwesterly extension of the same axis from the Drumright dome the oil in the Bartlesville sand lies more than 1,875 feet below sea level. On the northeast side of the Drumright dome the lowest oil lies between 1,625 and 1,650 feet below sea level. The southwest side of the Drumright dome is complicated by folding and no information about it is available.

The Shamrock dome furnishes more information. On the northeast and east sides the lowest oil lies from 1,700 to 1,725 feet below sea level, and oil fills the Bartlesville sand on the Shamrock saddle to the south, although its highest point lies about 1,775 feet below sea level. The line dividing the oil from the water on this side of the dome trends southward and crosses the structure contours to a point east of the Shamrock saddle, where the lowest oil is found between 1,800 and 1,825 feet below sea level. On the east side of the anticline in the northern part of T. 16 N., R. 7 E., the line between the gas and the water is about 1,775 feet below sea level, whereas on the southwesterly extension of this plunging anticline the lowest gas is about 1,825 feet below sea level.

Much detailed work might be profitably done, both experimentally and in the field, in connection with this interesting subject, which is obviously of great economic importance. If it can be determined that in domes and anticlines which are folded to a certain degree of intensity the oil is universally found lower on the long axes than on the steeper sides, this fact will be of great aid to geologists in the work of selecting lands for leasing, locating test wells, estimating oil content, and in considering the mode of accumulation of petroleum and natural gas. The present method of estimating the total oil content of an anticline or a dome after a few wells have been drilled in the middle of the productive area, and perhaps one or two into edge water, will necessarily prove inaccurate if the facts observed in the Cushing field are found to apply to other similar fields, because the elevation of the surface of edge water not only may vary greatly from one end of a large field to another, but the oil in a dome that is unaffected by other large folds and minor undulations will extend structurally much lower on the axes than on the sides, a fact that would introduce a great error in computing the total oil held in the crest of the dome by edge water.

DIRECTION OF MIGRATION OF OIL AND GAS.

The hydraulic theory of the accumulation of oil and gas is based on the assumption that the hydrocarbons were concentrated by a body of water that moved through a sand, and although the determination of the direction from which the Cushing field derived its oil and gas is not the primary object of this paper, the relations of the oil and gas bodies in this region indicate that they migrated from the west or northwest, because most of the gas in the field lies to the east and most of the oil to the west.

LAYTON SAND.

Plate VII (in pocket), which maps the oil and gas in the Layton sand, shows that in the district east and southeast of Drumright gas occupies the Layton sand in the area stretching eastward from the top of the anticline that extends southwestward through the Drumright dome over the Mount Pleasant dome to the eastern water line and that oil occupies the same sand in an area that lies west of the gas area and extends as far west as the western water line.

The same arrangement of oil and gas in the Layton sand occurs on the Shamrock dome, on the Shamrock saddle, and on the fold in the northern part of T. 16 N., R. 7 E., where nearly all the principal gas areas lie on the crests and the east sides of the folds and the oil areas lie on the west sides. With the exception of the Dropright

dome, only three areas on the eastern side of the field derive oil in commercial quantities from the Layton sand, and these areas lie, respectively, on the south slope of the Mount Pleasant dome, on the east side of the Shamrock dome, and on the east slope of the anticline in the northern part of T. 16 N., R. 7 E. Showings of oil have been found at many places in the Layton sand on the eastern side of the field, but the sand has produced only a small quantity of oil on this side of the field. Gas is obtained from the Layton sand on the crest of the Dropright dome, where it is surrounded by oil, but the heaviest production is obtained on the north and northwest sides of the dome.

WHEELER SAND.

The features indicated are shown even more plainly in the distribution of gas and oil in the Wheeler sand. A broad band in which the Wheeler sand produces oil extends from the southwest side of the Dropright dome southward through the town of Drumright, broadens out on the Wheeler terrace south of Drumright into a rich pool nearly 2 miles wide, and terminates in secs. 19 and 20, T. 17 N., R. 7 E. East of this broad band is a still larger area in which the same sand produces gas, which except at one place occupies all favorable structural positions as far east as edge water. This exception is a small area, less than half a square mile, that lies chiefly in sec. 10, T. 17 N., R. 7 E., in which the gas is trapped at the head of the syncline that separates the Mount Pleasant dome from the Shamrock dome. North and south of Shamrock the oil in the Wheeler sand lies well down on the west side of the uplift extending southward from the Shamrock dome to the anticline in T. 16 N., R. 7 E., though it has not been extensively developed, and the gas occupies the higher structural positions farther east and the eastern slopes of all the upfolds as far as the water line. In this area there is scarcely a trace of oil in the Wheeler sand.

On the Dropright dome the gas in the Wheeler sand is especially noticeable and in all the higher parts of the sand is under great pressure. Practically the whole of the Wheeler sand on this dome is occupied by gas except a small area of irregular structure in a part of sec. 5, T. 18 N., R. 7 E., where the oil, like that in the small area in sec. 10, T. 17 N., R. 7 E., has apparently been in some manner trapped and is almost surrounded by gas. Thus practically no oil has been produced from the Wheeler sand on the eastern side of the field.

BARTLESVILLE SAND.

Gas occupies the Bartlesville sand on the east side and crest of the anticline in the northern part of T. 16 N., R. 7 E., and oil occupies

it on the west side. On the southeast side of the Shamrock dome gas is very plentiful in the Bartlesville sand, is under high pressure, and is accompanied by but little oil, but on the west side of the dome the sand contains more oil and less gas. The crest of the dome in the Bartlesville sand contains gas under high pressure but little oil. In all the higher structural positions in the district north of the Shamrock dome the Bartlesville sand contains gas and oil. Gas is associated with oil on the crest of the Dropright dome, and the area containing it is entirely surrounded by oil.

RÉSUMÉ.

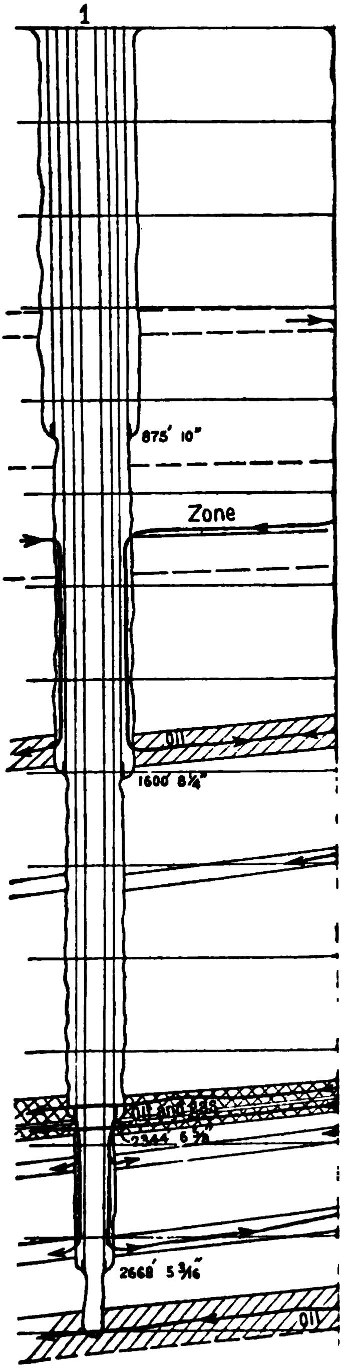
The unusual distribution of oil and gas in the sands in the Cushing field indicates that the source or gathering ground of the oil and gas was west or northwest of the field. The direction taken by them may be due in part to the fact that in the Cushing field, as in many other prolific gas and oil fields in northeastern Oklahoma, the dominant structural feature is an anticline on a great monocline, the fold having a short east limb and a long west limb. The gathering area is therefore practically all on the west limb. Gas first fills up the crest of the fold and acts as a barrier between the water on the east side and the oil migrating up the west limb. The oil, on account of its slower rate of movement through porous rocks, collects after the gas and forms a pool against the gas on the west or long limb. Although the evidence presented does not conclusively prove this, the facts related have been presented in the hope that they may be of use to others who are interested in this subject. Certainly if other pools in the same province are studied with the same objects in view and similar facts are determined, many interesting and valuable conclusions may be drawn, which will ultimately have an important bearing on the problem of oil and gas accumulation in the Mid-Continent field.

WATER IN THE SAND.

CLASSIFICATION.

In a sand that contains water, oil, and gas, the oil and gas generally occupy the higher structural positions, but in a sand that contains oil and gas but no water the oil and gas usually occupy the lower positions. In the Cushing field the three sands considered are saturated with water, which holds the oil and gas in the higher structural positions in each sand.

Water that is ordinarily a source of trouble in an oil field may be divided into three classes—(1) top water, which comes from a "sand" above the productive sand; (2) bottom water, which lies below the productive sand and is separated from it; and (3) edge water, which holds the oil and gas in the higher structural positions.



SKETCH SHOWING HOW T

Diagram compiled fı

TOP WATER.

The water in the Cushing field, except the shallow fresh water found at depths of 100 to 300 feet, from which the domestic and field supply is obtained, consists of salty and sulphurous waters that lie at different depths. The fresh waters do not ordinarily flow but stand about 100 feet from the surface. The force of gas, however, sends forth from some wells in the northern part of the field 5,000 or more barrels of water a day, a fact that has led some to believe that the water is artesian.

In the logs of many wells salt water has been recorded between the fresh water and the Layton sand, and also just above the tops of both the Layton and Wheeler sands.

Water is giving many operators in this field considerable difficulty, which can not be attributed to edge water and which could have been avoided by reasonable cooperation between drillers and by proper methods of drilling and protecting the productive sands. Many wells have not been properly cased and packed. An example of bad packing and casing is seen in Plate XI. In the Cushing field the operators of adjacent wells, through either indifference or ignorance, in their haste to reach the lower productive horizons, have failed to work in harmony with one another. Top water is thus allowed to circulate back and forth among the sands between two neighboring wells and to find its way into the main productive sands, which it floods. Many such floodings have occurred in the Cushing field, and nearly all of them have been due to a lack of foresight and of cooperation among the operators and to their refusal to adopt methods that would protect the sands.

BOTTOM WATER.

In some oil fields the producing sand is separated from the water sand below by a bed of relatively impervious shale of varying thickness, and great care must be exercised to stop drilling before this bottom water is reached, as in some places it is under great pressure, which makes its exclusion from a well difficult. The Cushing field is not much troubled with water of this sort, however, although many operators believe they have drilled into bottom water when they strike edge water. At some places water occurs under great pressure interstratified with the oil and gas in the Bartlesville sand, and these streaks, which are separated by "breaks," or thin beds of shale, often lead the drillers to believe they have drilled into bottom water. There is an unusually large number of water streaks in the Bartlesville sand on the crest of the Dropright dome. Below and above these streaks at some places there is excellent oil and gas "pay," so that the operators, after producing first from the upper "pay," drill through the water into the next "pay." Whether it was impos-

sible to case through this water or whether the operators considered it unnecessary, some of them failed to do so. Moreover, after a few days some of the heavy gas streaks "came on" water. Then, as the water, gas, and oil streaks had not been separated the water flowed into the well and "cut" the oil and in a short time drowned it out.

Many of the operators have attempted to shut off the water but with little success. It can seldom be shut out by setting lead plugs in wells, for the "shell" in which the plug is supposed to make a water-tight joint may be badly shattered or broken by the drill, by shooting with nitroglycerine, or by the tremendous force due to the expulsion of the oil, water, or gas. This unusual composition of the Bartlesville sand in the northern part of the Cushing field is therefore a serious obstacle to the economic production of the oil and gas.

EDGE WATER.

Top and bottom waters that occur in beds separated from the producing sands by other formations have in a few wells been mistaken for edge water. A decrease in the oil content of a productive sand and especially a decrease in the gas pressure allows edge water to pass through the part of the sand that once was saturated with oil or gas, and although its advance may be temporarily retarded by various means, its access to the producing sands marks the end of every field that is "backed up by water."

Edge water usually encroaches on a field after much of the recoverable oil and gas have been obtained and after the gas pressure has become greatly reduced. Its encroachment can not be prevented, though it may be temporarily retarded by properly manipulating the tubing and pumps in the wells, by adopting certain cementing practices, or by forcing compressed air into the sand. In this way much oil may be obtained that would otherwise be lost.

Edge water has caused trouble in some wells in the northern part of the Cushing field and has led to the abandonment of many wells that tap the Wheeler sand on the Wheeler terrace. It has caused very little difficulty in wells in the southern part of the Cushing field, near Shamrock, and it has been reached by only a very few wells on the eastern edge of the field. Edge water advances rapidly in some parts of the Cushing field, probably on account of the rapid decline of the gas pressures, and wells that have ceased flowing are pumped with declining output, at length yielding a small settled production. The flowing life of the wells is short, and some wells in the Bartlesville sand with initial productions of 3,000 to 10,000 barrels daily soon decline to small pumpers. Wells that show this rapid decline are numerous. The average daily production of the

wells in a group in sec. 9, T. 17 N., R. 7 E., during one month was 450 barrels each. Eight months later the same wells were making 45 barrels each. Another group of wells drilled early in the exploitation of the field at first yielded an average daily output of over 1,000 barrels each, but during the fourth month after they were drilled they yielded only a daily average of 44 barrels each. A year later the same wells were making 11 barrels each. The wells of a group on the Dropright dome averaged nearly 2,000 barrels a day each during the first month of their life, but after three months their daily output had declined to 190 barrels a day each. The history of nearly all the wells drilled to the Bartlesville sand during the "boom" is similar, and the decline in the output of the field as a whole has been remarkably rapid.

The principal causes for the rapid decrease in production are the tremendous waste of gas during development due to improper construction and operation of wells, such as inadequate casing and packing, and the practice of drawing without reserve on the oil and gas supply. The initial production of most of the Bartlesville wells was large, but the practice followed produced a rapid decline in the closed gas pressure, which is the motive force in expelling the oil, so that the decline in the output of the wells has been extraordinarily rapid, and the ultimate production of the properties will be much smaller than if the field had been developed wisely.

NECESSITY OF EXCLUDING WATER FROM THE OIL AND GAS SANDS.

When the Layton and Wheeler sands no longer yield a profitable output the least productive wells are abandoned and plugged. Several such wells have already been so abandoned, especially in the area near Drumright, where most of the output was originally obtained from the Wheeler sand. If an abandoned well is properly plugged, it will not let water into a sand which may be producing oil and gas in a near-by well, but as an operator may not be able to determine when a well has ceased to be profitable he may temporarily cease pumping; and if the well is allowed to remain unpumped for more than a short time and it is making water, it soon becomes a great menace to all adjacent wells.

A prime necessity in the successful and economical development of an oil field, especially a field that is divided among a number of operators, is that the work be carried on uniformly and in close cooperation—that is, that the casing points and other operations should be the same in wells on adjoining properties in an area having the same geologic structure. (See Pl. XI.) If water is permitted to come into contact with oil in a producing well the oil pressure may at first exclude the water, but as the oil is reduced in volume

the pressure decreases and the water overcomes the oil, forming an emulsion which must be dehydrated on the surface to render it salable. The process of dehydration is not only expensive but it depreciates the value of the oil, because it drives off the more volatile constituents. The effect of the water on the quantity of oil produced may not be apparent in the first stages of its encroachment, but later the water will drive back the oil and replace it in the sand by ever-increasing encroachment until the well can no longer be worked profitably. Nor is the damage confined to the point where the water first enters; it progresses through the formation at a rate which depends mainly on the relative pressures of the oil, gas, and water, and the porosity of the sand, and eventually the oil will be trapped in minor irregularities in the sand, which are not likely to be reached by the drill.

The infiltrating water affects the gas the same as the oil, though more rapidly, because gas flows more readily than oil from a sand when replaced by water. A small quantity of water in the first stages of its intrusion in a gas sand can be handled by separating it from the gas by means of traps installed at the well. Later, however, the water will drive the gas back into the formation, trap it, and drown it out.

WATER SURFACES.

GENERAL CONDITIONS.

The expression "water surface" as here used denotes the level or inclined plane between the oil or gas in a sand and the edge water upon which the oil or gas rests. (See A, fig. 4.) This water surface must not be confused with the ground-water table, which in an undulatory region is not level and which is defined as the surface below which the rocks are saturated with water. The ground-water table conforms in a measure to the undulations and to the bedding and nature of the rocks. The water surface referred to in this report is the surface that is confined to one porous stratum and might also be spoken of as the "water level," if it were not inclined. It might be further defined as the surface of the edge water which holds the oil and gas in the higher structural positions in a porous stratum.

In the course of the inspection work in Oklahoma many difficulties with water were noted, and they were studied closely with a view of aiding the operators. It was decided at the outset to collect all available information about water and, if possible, to reach some conclusions as to the rate and method of encroachment of edge water and the original and present levels of the water in each sand on all sides of the Cushing field.

The only wells that afforded information regarding the water surface—that is, the surface of the edge water in an oil and gas sand—are those that pass through the oil directly into water, such as the westernmost well shown in A, figure 4. If a well were drilled a considerable distance west of this well it would pass directly into the water after it had penetrated the sand. Such a well affords no valuable information, and unless the driller records the depth to which the water rises in the well, which he rarely does, the informa-

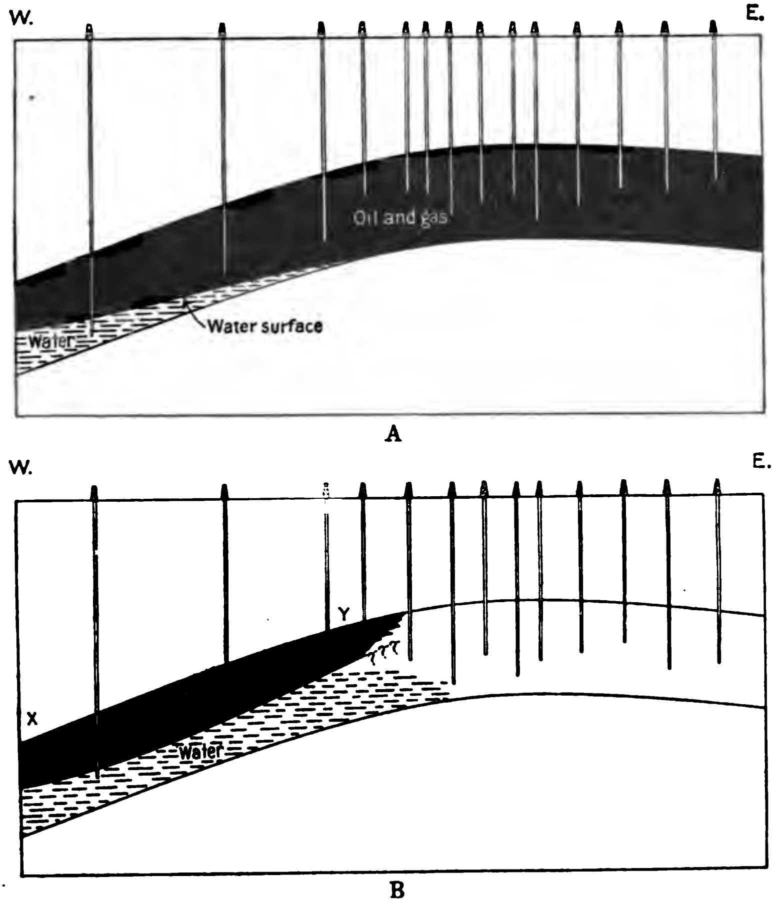


FIGURE 4.—Sketch showing the probable inclination of the water surface in the northern part of the Cushing field before and after development.

tion available shows only that the water surface lies higher than the roof of the reservoir at that point. (See A, fig. 4.)

After all the logs had been collected, the depths below sea level at which the water surfaces were reached were plotted on a map. But these depths are very different, a fact which made it necessary to determine, if possible, the cause of such differences, and which led to a study of the surfaces of edge water in the several sands.

As the height of the water in any sand may change materially in a few months after some of the oil and gas are taken from the sand, the date of completion of every well drilled to edge water was noted, and furthermore, as faulty methods of operation may allow intercommunication between sands and may cause the oil and gas sands to be filled with top water, it was also necessary to consider the character of the operations.

The investigation has disclosed some interesting facts which, if taken in connection with similar facts disclosed by studies in other fields, may help to solve the problem of oil and gas accumulation in the Mid-Continent field and may throw light on the rate and method of encroachment of edge water. Moreover, such detailed knowledge of the relations that exist between the oil and gas and the water in the same sand may enable geologists to determine more accurately, previous to drilling the underground conditions in similar fields.

The most important disclosure is the fact that the water surfaces upon which the oil and gas rest in the Layton, Wheeler, and Bartlesville sands are not horizontal, and not only lie at different elevations on different sides of the domes but are also inclined away from the center of the upfolds, conforming roughly to the structure of the oil sand but not dipping so steeply as the roof of the reservoir in which the oil and gas are contained. (See fig. 3.) Not enough wells have been drilled to edge water, however, to determine the attitude of the water surfaces in all parts of the field. Plates VII, VIII, and IX show the inclinations of these water surfaces in the Layton, Wheeler, and Bartlesville sands. The interval between the contours, except those for the Bartlesville, is 10 feet. The data used in constructing the Bartlesville contours were insufficient to determine the location of all the lines, so only the lines representing depths of 1,750, 1,800, and 1,850 feet below sea level were drawn for the northern part of the field, where a line was drawn in the district east of Drumright to represent a depth of 1,870 feet below sea level.

These contours do not show accurately in detail the shape of the water surfaces in the sands; they show only the general form of the water surfaces; no attempt was made to make them conform to the irregularities in the structure of the sands. The only object in drawing the contours has been to show that the surfaces of the edge water in the different sands are not level but are inclined away from the centers of production and structure. Many large errors may creep into work of this sort, as all the information is obtained secondhand or third-hand from the driller who made the observations, but the information used is believed to be sufficiently trustworthy to afford a substantial basis for the conclusions presented.

LAYTON WATER SURFACE.

By referring to Plate VII it will be seen that the Layton water surface conforms very closely to the geologic structure of the Layton sand, the syncline on the north side of the Dropright dome and the anticline extending northeastward from the crest of the same fold defining the water surface very clearly. The water surface appears to be nowhere horizontal or inclined toward the center of the field.

The maximum dip of this water surface on the northwest side of the Dropright dome amounts to 100 feet in a little over half a mile. The dip from the north line of sec. 9, T. 18 N., R. 7 E., to a point due north as far as it was possible to obtain trustworthy information amounts to 90 feet in a mile. The dip on the east side of the Dropright dome from the property of the Producers Oil Co., NE. ¼ sec. 9, T. 18 N., R. 7 E., to the B. B. Jones well, in sec. 10, amounts to 100 feet, and the distance is approximately a mile. On the west side of the Wheeler saddle, where the most contours were determined, the dip amounts to about 90 feet in a mile.

In the Layton sand in the north part of T. 18 N., R. 7 E., and the south part of T. 19 N., R. 7 E., the water occurs from about 660 to 700 feet below sea level. The water surface on the west side of the Dropright dome is variable, ranging from about 600 to 700 feet below sea level. In the Layton sand on the west side of the Wheeler saddle the water lies at depths below sea level ranging from about 620 to about 700 feet, the greater depths lying to the west. The inclination of the water surfaces in the Layton and Wheeler sands and the relation of the oil, gas, and water in the sands are shown in figure 3 (p. 30).

The water surface in any sand on the sides of the Mount Pleasant dome could not be determined, and in the area east of Shamrock not many wells have been drilled into edge water. The water surface on the west side of the dome in the northern part of T. 16 N., R. 7 E., lies between 575 and 600 feet below sea level, which is the shallowest depth at which any edge water has been found in the Layton sand around the edges of the Cushing field. In this locality Layton oil was first struck in September, 1915, and it has been possible to determine two certain contours on the Layton water surface. Inasmuch as practically all the wells in this area were drilled within a very short period these contours probably show the original inclination of the water surface. The dip of the water surface amounts to about 20 feet in a little more than a quarter of a mile, and the contours follow the geologic structure very closely.

WHEELER WATER SURFACE.

The information available as to the water surface in the Wheeler sand (see Pl. VIII) was less than that compiled for the Layton sand. In the district west of the Wheeler saddle and on the Wheeler terrace, however, the water surface slopes toward the outer edge of the pool, as it does in the Layton sand around the Dropright dome, and if more wells had been drilled to water in the Wheeler sand the results determined would probably have been as great as those reached for the Layton sand. The Layton sand, however, has been penetrated oftener than the Wheeler sand because the areas of oil and gas in the Wheeler sand are a little more widespread than those in the Layton sand, and because it has not been wise to drill below the Wheeler sand in many places on account of the smaller areas of oil in the Bartlesville sand. For these reasons water has been encountered more often in the Layton sand than in either the Wheeler or the Bartlesville sand.

The maximum dip in the Wheeler water surface is 40 feet in about three-fourths of a mile on the Wheeler terrace, and just south of Drumright the westward dip is about the same. The elevation of the water surface on the west side of the Wheeler terrace ranges from 1,400 to 1,460 feet below sea level. Sufficient information is not available to determine the attitude of the water surface on the Dropright dome, as most of the wells that reached the Wheeler sand found gas, and water has seldom been recorded in the logs as occurring in the Wheeler sand.

On the southwest side of the Dropright dome and on the west side of the Wheeler saddle water has been struck in the Wheeler sand in a number of wells at depths ranging from about 1,400 to about 1,460 feet below sea level, the lower depths being on the west. (See fig. 3, p. 30.) On the east side of the main anticline that extends northward from the Shamrock dome the Wheeler water surface was found in one well at 1,331 feet below sea level, a fact which indicates that the water on the east side of the dome is higher than that on the west side. This difference in level is further indicated by the fact that on the south slope of the Mount Pleasant dome the Wheeler sand was full of water at 1,360 feet below sea level, and the water surface in that locality must, of course, lie above this level.

On the west side of the dome, in the northern part of T. 76 N., R. 7 E., water was encountered in the Wheeler sand at 1,397 feet below sea level, and as it was found near the bottom of the sand this is probably about the highest elevation at which water occurs in the Wheeler sand in that locality. This level coincides closely with the highest level of the water surface on the west sides of the Wheeler saddle and Wheeler terrace.

BARTLESVILLE WATER SURFACE.

The Bartlesville sand is much more difficult to deal with, for it includes not only oil, gas, and water sands of different porosities but thin shale partings. At some places high up in the sand a streak of water under pressure was found by a few wells, which led the drillers to decide that "bottom water" had been struck, and it was so recorded in the logs. On the other hand, in many wells in the same vicinity this streak contains gas or oil, or the driller may have proceeded in spite of the water and found oil below. The records, therefore, show many depths to water in the Bartlesville sand, so that the information concerning the water surface is of much less value than that afforded by logs of wells sent to the Layton and Wheeler sands. Nevertheless a few of the principal contours on the water surface in the Bartlesville sand have been drawn by using only the depths at which the actual edge water is presumed to have been encountered without regard to any preconceived idea as to how the contours should run.

In the Bartlesville sand on the north, west, and east sides of the Dropright dome the water ranges in depth below sea level from about 1,700 to 1,850 feet, the water of lesser depth generally lying near the axis of the fold. The maximum dip of the Bartlesville water surface seen on the Dropright dome is 80 feet in about half a mile.

Water occupies the Bartlesville sand on the Wheeler saddle and on the Wheeler terrace near Drumright. East of Drumright, where many excellent Bartlesville wells have been drilled, the water surface lies 1,700 to 1,830 feet below sea level, but not enough information was available to determine definitely the shape of the water surface. South and east of Drumright the water surface ranges from about 1,725 to 1,825 feet below sea level, but the data were too scanty to determine any contours. Water is found at two places in the Bartlesville sand on the east side of the Mount Pleasant dome at depths of 1,842 to 1,848 feet below sea level, and near the crest of the dome water has been recorded in two places at depths of 1,740 and 1,741 feet below sea level. Near Shamrock water occurs at depths ranging from about 1,800 to 1,875 feet below sea level. It is thus apparent that the water surface in this vicinity is slightly lower than in other parts of the Cushing field. South of Shamrock, on the west side of the dome in the northern part of T. 16 N., R 7. E., water is found at two places, not far apart, at depths of 1,870 and 1,872 feet below sea level.

VARIATIONS IN THE WATER SURFACES AROUND THE CUSHING FIELD.

An interesting and important feature observed is the fact that the water surfaces in the three different sands studied are very irregular

in shape, as may be seen by referring to the outer limits of oil or gas in the different sands shown on Plates VII, VIII, and IX. The line limiting the productive oil or gas territory defines the areas inside of which oil or gas has been found and outside of which only water occurs. Although a line on the map separates the area containing oil from the area containing water the two are in reality separated by a warped plane. The line represents the intersection of this plane and the surface of the sand contoured.

As has already been noted, the planes that separate the oil and water bodies in the three different sands lie higher on the steep sides of the domes and anticlines than on the slopes on their longer axes. For instance, the line representing this plane in the Layton sand on the Dropright dome lies about 600 feet below sea level on the east and west sides of the dome but about 650 feet below sea level on the north side. This feature is characteristic not only of the Dropright dome; it predominates in practically all the domes and anticlines in all the commercially produced sands in the Cushing field.

The water line in the Layton sand—that is, the line representing the warped water surface—ranges in depth below sea level from about 575 feet at the south end of the field to about 650 feet on the west side of the Wheeler terrace and Wheeler saddle. On the sides of the Mount Pleasant dome and on the east side of the Shamrock dome this line rises much higher.

The water line in the Wheeler sand around the Cushing structure is much more variable than the water line in the Layton sand; it rises as high as 1,250 feet below sea level on the east side of the Shamrock dome, and is found as low as 1,475 feet below sea level on the west side of the Wheeler terrace.

The water line in the Bartlesville sand around the Dropright dome ranges from 1,650 to 1,800 feet below sea level, which is about the same range observed in other parts of the Cushing field.

As a matter of fact the water line—the intersection of the warped plane of the water surface and the surface of the oil sand—should be the boundary outside of which no water-surface contours are drawn. This is not true, however, because the statistics from which the maps were drawn are not complete nor absolutely accurate. For example, a well drilled some distance outside the oil area as represented may have obtained only a showing of oil but may have furnished sufficient information about edge water to enable the determination of water-surface contours, yet the showing of oil was so slight that the well was not included in the oil area.

If full and absolutely accurate information were available, the point of intersection of a structure contour and the water line would

be a point on the outer end of a water-surface contour, but the maps do not show this, because trustworthy information was not available for their preparation, and because the water-surface maps were prepared separately from the structure-contour maps and are designed to show only the general warping of the water surface.

POSSIBLE CAUSES OF THE INCLINED WATER SURFACES.

It may occur to some that the inclination of the water surface in adjacent wells that were completed on widely different dates may be apparent only—that the water may be reached first on the edge of a pool, and then, after much oil and gas have been extracted from the sand, the level of the edge water may rise so that in the wells drilled later, near the center of the field, the water may be found higher on account of encroachment. This method of development, however, has been followed in but few oil fields, for development ordinarily proceeds outward from the richest part of the field. Where "wildcatting" is being carried on in an undeveloped territory a dry hole is seldom offset, and a small oil producer only occasionally; but if an excellent producer is drilled it is immediately offset and probably several times if the land is divided among many operators, as it usually is. Then if any of these offset wells proves a still better producer, more wells are drilled farther in that direction, as the constant ambition of operators in "wildcatting" is to discover the center of the pool, where they naturally expect to obtain the greatest output.

The contours showing the water surfaces in these three sands (Pls. VII, VIII, and IX) are based on information which indicates that the water surfaces apparently slope away from the centers of production. This inclination of the water surfaces may have existed originally, prior to the development of the field, or it may have been wholly a result of the extraction of oil and gas, or if it existed before the field was exploited it may have been rendered greater by the extraction of oil and gas. If the inclination existed before the field was developed, it may have significant connection with the mode of accumulation of the oil and gas; if it has been acquired since development began, a study of its causes may contribute to our knowledge of the drainage of oil sands; if it existed prior to development and was made greater by the extraction of oil and gas, its study may afford valuable conclusions both as to the mode of accumulation of the oil and gas and as to the drainage of the sands. If the water surfaces were originally inclined or if the inclination is due wholly to the rapid extraction of oil and gas, certainly the oil, water, and gas must be in a state of unstable equilibrium during the period of this inclination. It is possible that such a disturbed equilibrium might exist after exploitation has begun, because the

removal of millions of cubic feet of gas under great pressure and the rapid expulsion of thousands of barrels of oil, even if no other factors entered the problem, certainly must cause many interesting and apparently unexplainable phenomena. It therefore becomes necessary to decide, if possible, just when this inclination was acquired and then to suggest some plausible explanation for it; but if no such explanation can be suggested, the best that can be done is to make a record of the facts, which, after they have been correlated with similar facts collected by others, may furnish some satisfactory explanation of the conditions observed. This record has accordingly been made, and in making it much information has been collected and classified according to the three possibilities enumerated above—that is, information afforded by logs of wells completed on approximately the same dates during the early history of the field has been considered separately from that afforded by logs of wells completed later, and the information of the two kinds has then been compared or contrasted to determine whether or not the third possibility might be considered.

The most significant available evidence indicating the existence of the inclination prior to development is found in the logs of wells drilled at the extreme southern end of the Cushing field, where the discovery of the productivity of the Layton sand about 2 miles south of Shamrock in September, 1915, caused rapid drilling by many companies in secs. 4, 9, and 16, T. 16 N., R. 7 E. (See Pl. VII.) On the west side of the anticline in the north part of T. 16 N., R. 7 E., the depths at which water was found in two wells are 578 and 587 feet below sea level, and on the south side of the same fold water has been found in three wells at 568, 575, and 588 feet below sea level. The highest elevation at which water is found is 568 feet and the lowest 588 feet below sea level, indicating that the inclination of the water surfaces of the Layton sand is original, although the information is too meager to prove this decisively. Practically all the wells drilled to the Layton sand at the extreme southern end of the field were completed within a period of three or four months. The production of these wells was not large, the closed pressure of the oil and gas in the Layton sand was not great, and the wells were economically spaced. Therefore, even if the wells had been completed through a longer range of time, the water surface probably would not have been so greatly affected by factors connected with production as it would have been in a field where the wells had larger initial production and were drilled closer together.

Similar corroborative evidence that the present inclination of the water surface was at least in part original and was not altogether the result of the exploitation of the field is found in the logs of wells

drilled on the north side of the Dropright dome to the Dayton sand. Here two wells were completed during November and December, 1913, in the SE. ¼ sec. 5, T. 18 N., R. 7 E. The one completed in November struck the Layton sand at 583 feet and struck water at 637 feet below sea level. The one completed in December, which is about a quarter of a mile northeast of the other, struck the Layton sand at 622 feet and water in the sand at 660 feet below sea level. As these wells were completed early in the exploitation of the field their logs probably show the true level of the water surface in the Layton sand, before much oil and gas had been removed. Between the two wells the beds dip 39 feet to the northeast and the water surface dips 23 feet in the same direction.

In a well in the center of the SW. ¼ sec. 5, T. 18 N., R. 7 E., completed in October, 1913, the Layton sand was struck 603 feet and water 631 feet below sea level, whereas in a well about half a mile to the west, in sec. 6, completed in November, 1913, the Layton sand was struck 568 feet below sea level and water 622 feet below, the difference indicating an eastward dip of the strata of 35 feet and of the water surface of 9 feet between the two wells. A comparison of the well completed in November, 1913, with a well about half a mile farther west, completed in December, 1913, which struck the Layton sand at 592 feet and water at 632 feet below sea level, indicates a westward dip of the beds of 24 feet and a dip of the water surface of 10 feet. The well just mentioned, completed in December, 1913, may also be compared with one a quarter of a mile to the south, completed in November, 1913, which struck the Layton sand at 563 feet and water in the Layton sand at 628 feet below sea level, the difference indicating that the beds dip to the north 29 feet and that the water surface dips 4 feet in the same direction. Many similar data have been compiled from logs of wells drilled in other parts of the Dropright dome and on the Wheeler saddle. Thus, the dip on the water surface in the Layton sand appears to be considerably less than that on the Layton sand itself as determined from logs of wells completed early in the exploitation of the field.

The information gathered suggests that the inclination of the water surfaces existed prior to development of the field and was probably due to the forces that controlled the accumulation of the oil and gas, among which are the friction of low-dipping beds, the difference in the viscosity of oil and water, the differences in the porosity of the sands, the compressibility of gas, and the incompressibility of oil and water. It is also possible that the water in these sands was originally level, but that folding subsequent to the accumulation of oil and gas inclined the water surfaces. Much experimental work might be done on this subject with profit.

Whatever may have been the causes of the original inclination, it is possible that it may have become greater after the development began on account of the operation of various factors connected with production. This possibility is indicated by some of the evidence, and the following is given to show the character of the detailed data used in considering this problem and in constructing the contours of Plate VII.

In a well drilled near the center of the SW. ¼ sec. 5, T. 18 N., R. 7 E., completed in October, 1913, early in the exploitation of the field, the Layton sand lay at 606 feet and the water surface at 634 feet below sea level. Just two years later, after much oil had been taken from that district through this and other wells, a well was completed about half a mile to the northwest, along the east line of sec. 6. In this well the Layton sand lay at 641 feet and water at 651 feet below sea level, indicating a northwesterly dip of the Layton sand of 35 feet and of the water surface of 17 feet between the two wells.

In the SE. ¼ sec. 6 a well completed in February, 1913, struck the Layton sand at 580 feet and water at 605 feet below sea level. Another well one-fourth of a mile to the northwest, completed in December, 1915, nearly three years later, encountered the Layton at 615 feet and water at 655 feet below sea level, showing a northwesterly dip of the beds of 35 feet and of the water surface of 50 feet between the wells.

A well near the center of the SW. ¼ sec. 5, completed in October, 1913, encountered the Layton sand at 603 feet and water at 631 feet below sea level. Another well about three-fourths of a mile to the northwest, in the NE. ¼ sec. 6, completed in November, 1915, struck the Layton sand at 623 feet and wate rat 703 feet below sea level, indicating a northwesterly dip of the beds of 20 feet and of the water surface of 72 feet between the two wells. Still another well, near the center of the south line of sec. 6, completed in November, 1913, struck the Layton sand at 570 feet and water at 616 feet below sea level, whereas a well about half a mile to the north, near the center of the section, completed in June, 1916, struck the Layton sand at 680 feet and water at 730 feet below sea level, indicating a northerly dip of the beds of 110 feet and of the water surface of 114 feet between the wells.

If, therefore, we can assume that the dip of the water surface is adequately determined by two wells drilled at widely different dates, then the water surface has been farther inclined by the extraction of oil and gas. The dip of the water surface, however, has been determined by evidence afforded by two wells drilled at different dates, and in the interval that elapsed between the drillings there

certainly must have been a change in the level of the water surface in the first well on account of the extraction of oil and gas. Therefore, the actual dip of the water surface between these two wells is not known, but it must be greater than that given for each well, because of the reduction in the volume of oil and gas in the sand during the period between the drilling of the two wells. Hence, evidence from wells completed at widely different dates gives smaller dips than those actually existing, especially if the first well is drilled nearer the center of production. The data serve just as well, however, to prove that the water surfaces have been further inclined. The dips actually existing on the water surface after much oil and gas have been extracted will be determined by selecting favorably located wells drilled on nearly the same date during the later history of the field.

Records of such wells completed on approximately the same date late in the exploitation of the field corroborated the above conclusion that the water surface has been further inclined by the extraction of oil and gas. For instance, one well, completed in June, 1915, near the center of the NW. ¼ sec. 4, T. 18 N., R. 7 E., struck the Layton sand at 615 feet and water at 647 feet below sea level and another, completed in July, 1915, at a point 600 feet north of the first, struck the Layton sand at 634 feet and water in the sand at 669 feet below sea level, the difference indicating a northerly dip of the beds of 19 feet and of the water surface of 22 feet between the wells. The log of the well last mentioned, completed in July, 1915, if compared with that of a well half a mile northeast, completed in April, 1915, which found the Layton sand at 635 feet and water at 641 feet below sea level shows a northeasterly dip of the beds of 1 foot and a southwesterly dip of the water surface of 28 feet. A comparison of the log of the well completed in July, 1915, with that of another well, completed in September, 1915, in the SE. ¼ sec. 33, T. 19 N., R. 7 E., which encountered the Layton sand at 653 feet and water at 702 feet below sea level, shows a northeasterly dip of the beds of 29 feet and of the water surface of 33 feet between the wells. A well completed in July, 1915, in the SW. ¼ sec. 8, T. 18 N., R. 7 E., struck the Layton sand at 508 feet and water in the sand at 520 feet below sea level. About a mile to the northwest a well that was completed in the same month struck the Layton sand at 551 feet and water in the sand at 614 feet below sea level, the difference indicating a northwesterly dip of the beds of 43 feet and of the water surface 94 feet between the wells.

Thus the information compiled from logs of wells completed during the early stages of the exploitations of the field and that compiled from wells completed during the late stages, when considered separately and contrasted, indicates that the water surface has been

further inclined, for at many places the inclination of the water surface is now greater than that of the roof of the reservoir.

Similar data indicate that the same condition exists at some places in the Wheeler sand. Figure 4 shows diagrammatically the inclination supposed to exist before and after development in the northern part of the Cushing field.

The causes of this additional inclination have not been clearly determined, but probably one cause is the difference in the viscosity of oil and water, which allows the water to be forced more readily up the dip through the sand. This cause probably operated as follows:

Before any oil or gas was produced the water surface was inclined, as shown in A, figure 4; the dip of the water surface was then less than that of the roof of the reservoir, and the closed pressure is assumed to have been the same throughout the reservoir. When the first well was drilled into the oil sand the gas expanded through the opening and carried oil with it. Each barrel of oil that flowed from the sand near the well reduced the pressure at that locality a certain amount. In a few months many wells were drilled into the highest part of the dome, which had by that time been well defined, and oil and gas were being rapidly expelled. This rapid expulsion of the oil and gas reduced the pressure in the sand over a wide area, so that it was less in that area than it was down on the edges of the pool, where fewer wells were producing, and those that were producing were expelling much smaller quantities of oil because less gas is absorbed in the oil on the flanks of an anticline or dome. The water beneath the oil, being under pressure and less viscous than the oil, was forced through the sand below the oil to the area of less pressure, causing the condition shown in B, figure 4, and a continuation of this operation probably caused the water surface to become inclined more than the roof of the reservoir.

In a distance of half a mile the Layton sand, at one place, as noted above, dips 1 foot to the northeast and the water surface dips southwest 28 feet, facts apparently not in harmony with the others given. This reverse dip of the water surface is thought to be due to the fact that the well on the northeast is drilled into a rich part of the Layton sand, to which many other wells have been drilled and from which much oil and gas have been extracted. This well, therefore, illustrates the explanation just given.

It is therefore possible that the wells in a very productive area on the crest of an upfold in beds of gentle dips will begin to show water as soon as or before those that are drilled lower on the domes or anticlines, and later, after the wells in the more productive areas yield very little oil and much water, a small deposit of oil may still remain on the sides of the domes or anticlines, as shown between

X and Y in section B of figure 4 (p. 49). Sufficient information has not been obtained in any part of the Cushing field, however, to prove or disprove this idea, and it is given here for what it may be worth.

NECESSITY OF SIMILAR WORK ELSEWHERE.

A search through many publications on the geology of oil and gas disclosed no report or paper on the inclination of water surfaces in oil sands.[1] The results outlined above are therefore thought to be important, but though there is no reason to doubt the trustworthiness of most of the data upon which the results are based it is not considered desirable to advance any but tentative theories to account for the phenomena or to offer the evidence in substantiation of theories already formulated until similar information has been gathered in other districts in the Mid-Continent field.

The writer believes that the study of the laws governing the accumulation of oil and gas is in its infancy and that many of the investigations made to determine those laws have not been directed along proper lines. A study of all the fields in a great productive province would aid this work, but before positive results can be obtained each important field should be separately studied and all facts that would show the relations of oil, gas, and water—their distribution and their relations to one another and to the structure—and any other pertinent facts should be collected and analyzed. As fast as these studies are completed, the facts learned, garnished by as few theories as possible, should be placed before the public to stimulate similar investigations and to give other investigators the benefit of the studies.

A vast accumulation of facts will be necessary to explain some of the phenomena, for many factors are involved and sufficient knowledge can be obtained only by patiently and systematically gathering and recording all the facts. What is already known of the conditions under which petroleum and natural gas accumulate is of inestimable advantage to geologists in selecting prospective oil lands and in the location of test wells, but the advantage will be greatly increased if some of the factors which still remain unknown can be determined.

It is hoped that the facts here presented will stimulate other similar but more detailed studies on this subject, which will ultimately broaden our knowledge of the accumulation of oil and gas and show the changing conditions under which oil and gas exist during the development and productive life of a field.

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[1] Since this paper was prepared and transmitted for publication, John L. Rich, in a report on the "Oil and gas in the Birds quadrangle," published in Bulletin 33 of the Illinois Geological Survey, notes that the water surfaces in some of the pools in Illinois were inclined.

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CANNEL COAL IN THE UNITED STATES

BY

GEORGE H. ASHLEY

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ILLUSTRATIONS.

CANNEL COAL IN THE UNITED STATES.

By G. H. Ashley.

OBJECT OF THE REPORT.

The recent rapid growth of the chemical industries of the United States, due in part to the shutting off of outside sources of supply, has brought the country to a point where it can provide for its own chemical needs and can reasonably expect that its products may soon enter the world's markets. The rapid extension of the use of motor-driven vehicles and the urgent demand for a larger supply of high explosives have led to a greatly increased demand for the lighter hydrocarbons and for the chemicals that are obtained by the nitration of toluene and phenol, which are derived by distillation from by-products of the distillation of coal.

One result of this increased activity has been a demand for information about cannel coal, one of the richest substances in hydrocarbons known, though the availability of these hydrocarbons for this growing chemical industry has yet to be proved. These hydrocarbons are now obtained by the distillation of oil and as by-products in the destructive distillation of coal. The primary products of this distillation of coal are artificial gas and coke or coke alone; the primary by-products are tar, ammonia, and benzol. The facts that cannel coal does not yield a coke that may be used for the purpose for which most coke is now marketed and that its cost has been about double that of the coals now used for making gas or coke have heretofore prevented its employment as a source of gas or coke. The recent increased demand for these by-products, however, is putting them into the class of primary products, and if the demand continues to increase as it has of late new and independent sources of hydrocarbons must be utilized. This fact has recently led to an increasing number of inquiries of the United States Geological Survey regarding cannel coal and has led to the preparation of this report.

The work done on this report has made more evident the already well-known lack of any general discussion of cannel coal. Cannel

coal is mentioned incidentally in a great many publications but in most of them only as a matter of curiosity, and even if it may be mentioned in the text of a book it has seldom been noted in the index, so that in reviewing the literature it has been necessary to go over many books page by page. Most of the longer memoranda on the cannel coal of this country were made during or just after the period of great interest in cannel coal, between 1855 and 1860, or just before the discovery of our great reservoirs of petroleum. At that time it was the principal source of our oil supply, nearly 60 distilleries being in operation in the United States in 1860. The discovery of rock oil naturally knocked the bottom out of the "coal-oil" industry, but the new growing demand for hydrocarbons may lead to a revival of the mining of cannel coal. In this connection it is desirable to call attention to a fact brought out elsewhere in this report—that all so-called cannel coals are not equally valuable for producing oil and gas, notwithstanding the prices at which they may now be selling for use in grates; two cannel coals may be of equal value for use in grates and may therefore now bring the same price, but one may have twice the value of the other for distillation for oil or gas.

The present paper is not intended as an original contribution to the subject, though the writer has drawn on his own notes in describing many of the deposits mentioned, particularly those in Pennsylvania, Indiana, and parts of West Virginia and Kentucky. It consists of a preliminary review of well-known facts about the character, uses, and value of cannel coal and brief descriptions of workable deposits of cannel coal, including cross sections of the beds, and it gives such analyses of the coal as are available.

DEFINITION.

Cannel coal is a massive, noncaking, tough, clean, block coal of fine, even, compact grain, dull luster, commonly conchoidal cross fracture, having a typical low fuel ratio, a high percentage of hydrogen, easy ignition, long yellow flame, black to brown greasy streak, and moderate ash, pulverulent in burning. It is essentially a rock derived by solidification and partial distillation or oxidation of water-laid deposits consisting of or containing large quantities of plant spores and pollen grains and more or less comminuted remains of low orders of water plants and animals.

In such a deposit of decaying spore and pollen material, containing both vegetal and animal débris to which Potonié[1] has given the name "sapropel," there may be admixed greater or less quantities of mud or of woody or peaty material. The high volatile content and high hydrogen of cannel coal appears to be derived from the spore

[1] Potonié, Henry, Die Entstehung der Steinkohle, 5th ed., p. 3, 1910.

and pollen and waxy material and, to an unknown extent, from animal remains. The greater the admixture of woody or peaty material derived from the usually adjoining peat marshes, the more closely the cannel coal resembles chemically the associated bituminous coals and the smaller the proportionate yield of oil by distillation. Cannel coals in common with other coals also differ in character and value because of changes they undergo, first by decomposition and later by physical and chemical changes due to pressure and heat, especially to pressure due to the weight of superimposed rocks and to the horizontal thrusts that have locally folded and otherwise disturbed the earth's crust. The effect of these forces has been somewhat similar to that of slow distillation, driving off first the moisture, then the higher hydrocarbons, then the heavier hydrocarbons, and ultimately, if continued, nearly or quite all of the volatile hydrocarbons. It is evident that the deposit will be of greatest value as a source of oil at that point where the largest percentage of water and the smallest percentage of volatile hydrocarbons have been driven off. Such coal may be termed typical cannel. Coals which have not reached that rank may be called subcannels, and those which have much passed that point and have thus lost all their peculiar qualities may be called canneloid coals:

Typical cannel coal is distinguished from bituminous coal by the following contrasting features:

Bituminous coal.	*Cannel coal.*
1. Laminated.	1. Massive.
2. Bright and dull bands.	2. Uniform velvety or satiny luster.
3. Prismatic fracture.	3. Conchoidal fracture.
4. Jointing imperfect.	4. Jointing regular and striking.
5. More or less friable.	5. Tough and elastic.
6. Disintegrates by weathering.	6. Weathers slowly; used for foundations of barns, etc.
7. Soils the hands.	7. Does not soil the hands.
8. Percentage of fixed carbon higher than that of volatile matter.	8. Percentage of fixed carbon typically lower than that of volatile matter (except in lean cannels).
9. Derived from woody or peaty deposits grown in place.	9. Derived mainly from spores, pollen, etc., brought in by wind and water.
10. Basins commonly extensive.	10. Basins rather small; many are narrow channels.
11. Commonly yields on distillation less than 10,000 cubic feet of gas to the ton.	11. Commonly yields on distillation more than 10,000 cubic feet of gas to the ton.
12. Candlepower of gas commonly less than 17.	12. Candlepower of gas commonly more than 20.
13. Commonly cakes in burning.	13. Does not cake in burning.
14. Coke usually strong.	14. Coke pulverulent.

Bituminous coal—Continued.	*Cannel coal*—Continued.
15. Yield of oil on distillation commonly less than one barrel to the ton.	15. Yield of oil on distillation from one to more than two barrels to the ton.
16. Less than 6 per cent hydrogen.	16. More than 6 per cent hydrogen.
17. Ignites with difficulty.	17. Ignites readily.
18. Streak commonly black.	18. Streak commonly brown.

CLASSIFICATION.

The subcannel coals may be divided into two ranks, corresponding to lignite and subbituminous coals, which may be distinguished as brown and black subcannels.

Cannels may be divided into two or three ranks—boghead cannels having a fuel ratio of 0.5 or less, named from their resemblance to the famous "boghead" of Scotland; cannels (including boghead), having a fuel ratio of 1 or less; and semicannels, having a fuel ratio of more than 1. A fuel ratio of 1 is a convenient point at which to draw the line between the typical and the lean cannels, but further research may show that it should be drawn a little higher or a little lower. This high fuel ratio may be due to dynamo-chemical changes, which decrease the percentage of volatile hydrocarbons, or to admixture of peaty elements in the original deposits, or to both.

If the fuel ratio of a cannel coal is more than 1 and the pure coal of the associated bituminous coal contains less than 65 per cent fixed carbon, the high fuel ratio is probably due to the presence of peaty elements in the original deposits. As such coals stand between bituminous and cannel coal they are properly called semicannels. On the other hand, low-volatile cannels that are associated with high-carbon bituminous coals may have been originally either nonpeaty cannels or peaty cannels. A detailed investigation of the constitution of these coals would doubtless reveal significant differences between these types and future distillation practice may disclose economic differences—in the yield of certain hydrocarbons, for instance. At present, however, for practical purposes they may all be considered lean cannels or semicannels.

Cannels that are associated with semibituminous, semianthracite, and anthracite coals and that have so far lost any peculiar advantage over the coals with which they are associated as not to be separated in mining, marketing, or use may be classified, according to their nature, as canneloid, semibituminous, semianthracite, or anthracite.

Cannel coals may therefore be classified, largely in genetic sequence, as follows:

1. Subcannel coal:
   - (*a*) Brown subcannel, of brown coal or lignite rank.
   - (*b*) Black subcannel, of subbituminous rank.

2. Cannel coal of bituminous rank:
   (*a*) Boghead cannel (fuel ratio less than 0.5).
   (*b*) Cannel, typical (fuel ratio less than 1).
   (*c*) Lean cannels or semicannels (fuel ratio more than 1).
3. Canneloid, semibituminous, semianthracite, or anthracite coal.

The grade of a cannel coal varies with the amount of ash or other impurity it contains. The bodies of water in which the cannels were laid down were at some places subject to inflows of mud, so that the deposit at such places might contain from less than 5 per cent to 100 per cent of ash, or might range from a pure cannel coal to a nonbituminous shale. The line between a coal and a shale has never been sharply drawn, but the suggestion is here made that material which, when burned, breaks down and yields an ash that goes through the grate bars and shows no tendency to maintain its original shape is a coal, and that material which on burning yields an ash that tends to maintain its original shape is a shale. The exact percentage of ash that should distinguish a coal from a shale can not yet be given, but until more exact figures are available it is suggested that material that yields less than 33 per cent of ash be considered a coal.

High ash, though it reduces the grade of a cannel coal, does not necessarily mean that the coal will not yield a large proportion of hydrocarbons, for many original deposits were not laid down in peat bogs and so contain little woody material. Such deposits may therefore yield coal that is rich in oil-making elements even though they may be high in ash. Thus an analysis of Scotch boghead (p. 28) shows nearly 20 per cent of ash, but more than 70 per cent of volatile hydrocarbons and about 10 per cent of fixed carbon. Some of the boghead shales of this country will yield from a barrel to more than two barrels of crude oil per ton of rock. Thus, as David White has suggested, such coals may be arranged in a series ranging from cannels through boghead cannels and cannel bogheads to bogheads.

The Scotch boghead and other bituminous shales have long been distilled for oil, and such shales are abundant in this country. Nearly all the coals described in this report are cannel coals, but a few analyses of canneloid coals are given for comparison, and a typical brown subcannel from Arkansas, a black subcannel from Utah, and a subcannel from Texas are briefly described.

PHYSICAL PROPERTIES.

General appearance.—Cannel coal is a nearly dull black, homogeneous, fine-grained coal, much of it resembling black flint in fineness of grain and in fracture.

Block structure.—The bed is commonly split by vertical joints, many of which extend from the roof to the floor. These joints are

nearly everywhere regularly spaced and occur in two sets that run nearly at right angles to each other. As a result the coal may mine out in blocks having almost a square cross section and a thickness ranging from the full thickness of the bed down to a few inches. The size of the blocks depends on the distance between the joints. In some places such joints are several feet apart; and the coal may be mined out in cubes measuring several feet on an edge. More commonly it is mined in cubes the size of a man's head or smaller. (See Pl. I.) This cubical structure is shown on a small scale in Plate II, *B*.

Bedding, grain, and fracture.—Cannel coal generally shows no bedding or horizontal banding but is even grained or massive throughout. At some places, however, as at Boghead, Ky., blocks of coal that are greatly weathered may have somewhat the appearance of the charred edges of a burned book and may split along bedding places into thin sheets, one of which, measured by the writer, had a thickness of $\frac{1}{250}$ of an inch. In other cannels weathering brings out a wavy structure, possibly the results of ripple marks on the original deposit. A coal that will weather into thin sheets may, when unweathered, have the massive appearance and fracture of a piece of nontransparent black flint. The evenness of grain permits the coal to be carved into desk weights or other objects. Indeed, the well-known material jet, used for making jewelry, is only a variety of cannel coal. The cross fracture of cannel coal is generally conchoidal, like that of glass. (See Pl. II, *A*.)

In some districts the cannel coal is what is known locally as "bird's-eye" or "curly." The fracture surfaces of this variety are small and irregular. (See Pl. III.) The two varieties may be found in the same mine, as were two of the specimens shown in Plates II and III.

Cannel coal that occurs in rocks which have been subjected to folding or which have been under heavy stress lose their characteristic structure and fracture and may become friable or tender and acquire a fracture and structure like that of the surrounding bituminous or anthracite coal, which it then resembles chemically as well as physically, though the two are distinguishable. Thus, at the Lula mine, near Philipsburg, Center County, within a few miles of the eastern edge of the bituminous coal field of Pennsylvania, there is a coal that was evidently originally a cannel, as it still has the typical dull, satiny luster of cannel, but its fracture is only slightly conchoidal and that of most of it is similar to the fracture of the associated bituminous coal, which in that area is long grained. It has also become friable, and instead of breaking, as usual, into blocks that split readily with the bedding and only with difficulty across the

A.

B.

VIEWS SHOWING BLOCK OR CUBICAL STRUCTURE OF COAL.

A.

B.

VIEWS SHOWING FRACTURE OF CANNEL COAL.

bedding it may be shattered by a slight blow of the hammer into slivers or chunks 6 inches to a foot or more long and 2 or 3 inches through, whose longest diameter is perpendicular to the bedding planes; and if such a chunk falls only a few feet to the ground it is likely to break into pieces, none of which are more than 2 inches long by half an inch square; and if handled much, most of this coal will crumble to fine dust. Obviously, this structure is due to the intense pressure to which the coals and the rocks that contained it have been subjected. David White has called attention to lenses of anthracite that still have enough of the features of cannel to indicate that they were originally true cannel coals, though to-day they are true anthracite. (See pp. 16, 17.)

Luster.—Cannel coal has a dull, even velvety sheen, resembling that of a fine-dressed black leather—new harness leather. The curly variety, if examined at right angles to the bedding, shows a dead black matrix mottled by dully glistening spots. (See Pl. III.) Some "bird's-eye" cannel has an irregular pitted appearance, as illustrated by Hendrie.[1]

Streak.—The streak of cannel coal—that is, the color of the mark it makes when rubbed against some other substance—is brown to black. Typically it is an oily brown.

Specific gravity.—The specific gravity of pure cannel coals is less than the average of bituminous coals that contain the same percentage of ash, and in most cannels that have the same percentage of ash the larger the percentage of volatile matter the lighter the coal—that is, the less its specific gravity. The following table shows, first, the change in specific gravity with change of ash where the fuel ratio remains about the same; second, the change in specific gravity with change in fuel ratio where the ash remains about the same.

Relation of specific gravity to percentage of ash in cannel coal.

Locality.	Specific gravity.	Ash.	Volatile matter.	Fixed carbon.	Fuel ratio.
Haddix mine, Breathitt County, Ky [a]	1.21	3.00	48.9	47.0	0.96
Mouth of Troublesome Creek, Breathitt County, Ky. [b]	1.265	7.30	47.0	44.4	.94
Branch of Horselick Creek, Jackson County, Ky [c]	1.32	8.76	43.6	45.5	1.04
Holmes County, Ohio [d]	1.38	9.9	44.7	42.9	.96
Little's mine, Quicksand Creek, Ky. [b]	1.39	11.44	43.1	43.3	1.04
Flint Ridge, Licking County, Ohio [d]	1.43	13.2	40.2	44.0	1.09
Long Branch of Martins Fork, Harlem County, Ky. [e]	1.51	24.6	34.6	39.4	1.14

[a] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 27, 1910.
[b] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 221, 1884.
[c] Idem, p. 273.
[d] Newberry, J. S., Ohio Geol. Survey Rept. Progress for 1870, p. 420, 1871.
[e] Peter, Robert, op. cit., p. 265.

[1] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 89, 1894.

Relation of specific gravity to fuel ratio in cannel coal.

Locality.	Specific gravity.	Fuel ratio.	Volatile matter.	Fixed carbon.	Ash.
Boghead, Carter County, Ky [a]	1.14	0.42	64.1	27.0	7.9
South of Boonesville, Osley County, Ky [b]	1.16	.54	59.7	32.3	7.4
Nichols Fork of Frozen Creek, Breathitt County, Ky. [c]	1.18	.60	58.8	35.3	4.7
Colvin Bank, Magoffin County, Ky. [d]	1.235	.72	51.9	37.5	8.2
Haddix mine, Breathitt County, Ky. [e]	1.21	1.04	46.6	46.8	5.00
Lick Branch, Johnson County, Ky. [f]	1.291	1.34	38.2	51.0	8.8
Chinns Branch, Greenup County, Ky. [g]	1.33	1.39	36.9	51.2	7.1

[a] Owen, D. D., Kentucky Geol. Survey Fourth Rept. 1858-59, p. 114, 1861.
[b] Peter, Robert, op. cit., p. 315.
[c] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 221, 1884.
[d] Idem, p. 292.
[e] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 27, 1910.
[f] Idem, p. 275.
[g] Crandall, A. R., Report on the Chinns Branch cannel coal district: Kentucky Geol. Survey Repts. on eastern coal field, C, p. 6 [200], 1884.

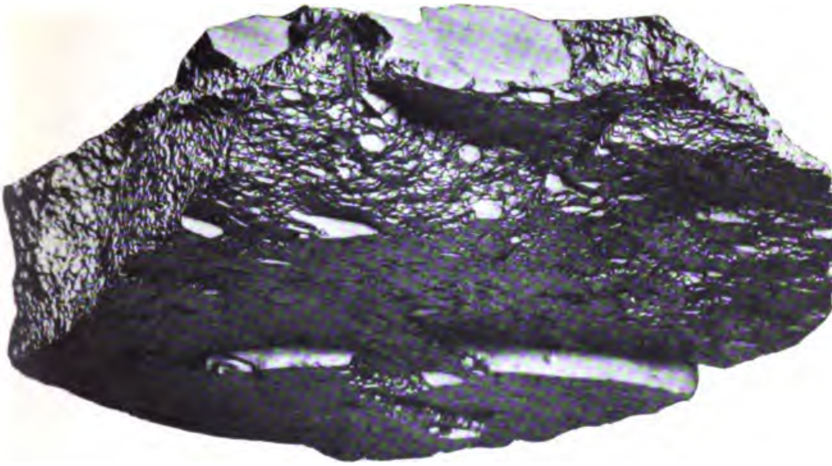
Were a large enough number of determinations made it might be possible to give, at least approximately, the relative weight-giving value of ash and fixed carbon. However, enough has been given to show the basis for the common rule that the lighter the cannel coal the greater its value.

COMPOSITION.

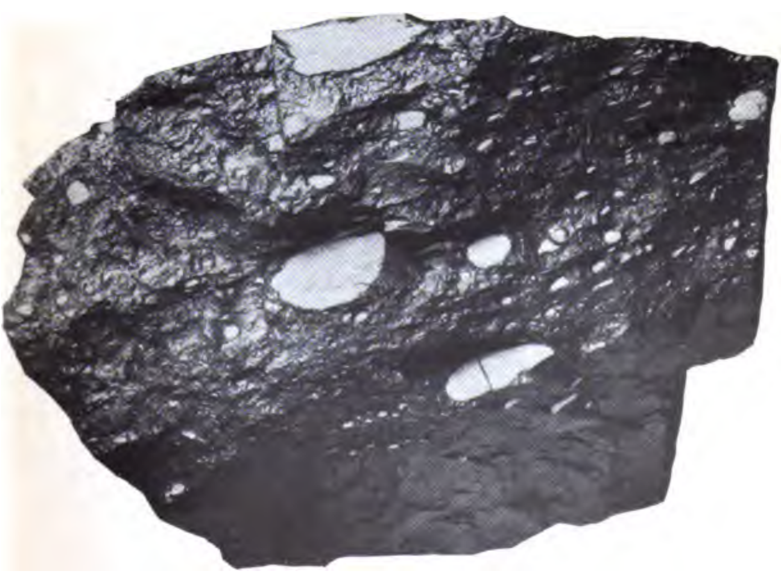
The composition of cannel coal is determined in three ways—by microscopic examination, by dissolving out its component parts by pyridine or other solvent, and by destructive distillation or analysis.

PHYSICAL COMPOSITION.

The fundamental differences between typical cannel coal and typical bituminous coal appear to result from the fact that they were deposited under different conditions and consequently were composed of different original substances, which formed different decomposition products. It is now very generally agreed that most coal is transformed peat. Cannel coal, however, appears to have been formed in part from decayed spores or pollen and other floating remains of plants, as well as of remains of minute or slow-moving animals, such as are commonly found to-day in the bottoms of lakes. In a peat bog decay is only partial, but in the more open waters of lakes or lagoons, whether surrounded by bogs or not, decomposition is likely to affect almost the whole mass of organic matter that settles to the bottom except the spore cases, or outer coverings of the spores, which are naturally very resistant, and some few other end products. These spores appear to have been mainly those of ferns and related plants, which were abundant during the Carboniferous period as well as later, and most of which were much larger and on the whole far more abundant than those of to-day. Associated with material



A.



B.

VIEWS SHOWING STRUCTURE OF "CURLY" OR "BIRD'S-EYE" CANNEL COAL.

of this type in some deposits of cannel coal, according to Newberry,[1] there are abundant remains of fish and other free-swimming animals. Many of the spore cases, though flattened, are well preserved; others are broken down into a pulp or ooze. According to Von Gümbel, Bertrand, Renault, and Thiessen[2] cannel coal, when viewed under the miscroscope in thin sections, consists mainly of spore cases in different stages of decay, with which are associated a very minor proportion of other bodies, like particles of resin, resistant seed coats, fragments of cuticle, and waxy bodies. In view of the difference in resistance to decay between the spore cases and the water-growing plants, such as algae, it may be doubted whether the presence of spore cases only should be taken as proof that spores have been the main source of the carbonaceous material. Associated with this pure coal matter is a greater or less proportion (10 to almost 100 per cent) of clay or sand, which forms the ash. As the proportion of shaly matter increases the coal changes to a bituminous or oil shale and locally to a nonbituminous shale.

CHEMICAL COMPOSITION.

COMPARISON WITH OTHER COALS.

Most cannel coals may be distinguished from other bituminous coals by the large proportion of high-candlepower volatile matter that is driven off from them at high temperatures or the large proportion of oil that is driven off at low temperatures and by the high percentage of hydrogen they yield on ultimate analysis. Doubtless more fundamental chemical differences would be found were it possible to determine exactly the chemical combinations existing in the coals, but no method of doing this completely has yet been devised. An ordinary analysis of coal may show either the proportions of the elements it contains or the products that may be obtained by heating the coal to a certain high temperature—the products differing according to the temperature and pressure applied.

By the usual methods of analysis, bituminous coals will yield from 45 to 75 per cent of fixed carbon and from 20 to 45 per cent of volatile matter. The fuel ratio of such coals—that is, the ratio of the fixed carbon to the volatile matter—will range from 1 or a little over for the coals of the Mississippi Valley to 2 or more for the coals in the eastern Appalachian field.

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[1] Newberry, J. S., On the mode of formation of cannel coal: Am. Jour. Sci., 2d ser., vol. 23, p. 214, 1857.

[2] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 88, pp. 248 et seq., 1913.

In contrast with these figures, typical cannel coals contain from 25 to 45 per cent fixed carbon and from 45 to 70 per cent volatile matter, or gas, the fuel ratio ranging from 1 down to 0.5 or less. This difference is shown by comparing the analysis of a sample of cannel coal with that of a sample of bituminous coal from a different bench of the same bed.

Analyses of cannel and bituminous coal from the same bed.

[C, cannel coal; B, bituminous coal.]

Locality.	Volatile matter.		Fixed carbon.		Ash.		Fuel ratio.	
	C	B	C	B	C	B	C	B
Boghead, Carter County, Ky.[a]	64.1	35.9	27.0	53.3	7.9	6.5	0.42	1.49
Troublesome Creek, Breathitt County, Ky.[b]	48.2	38.0	44.2	52.0	4.7	4.7	.91	1.37
Quicksand Creek, Breathitt County, Ky.[c]	66.2	39.6	29.7	48.0	3.6	10.6	.44	1.21
Chenoa, Bell County, Ky.[d]	51.6	32.6	40.4	62.3	7.0	3.4	.77	1.90

[a] Owen, D. D., Kentucky Geol. Survey Fourth Rept., for 1858–59, p. 114, 1861.
[b] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 27, 1910.
[c] Fohs, F. H., Coals of the region drained by the Quicksand creeks: Kentucky Geol. Survey Bull. 18, p. 77, 1912.
[d] Ashley, G. H., and Glenn, L. C., Geology and mineral resources of part of Cumberland Gap coal field Ky.: U. S. Geol. Survey Prof. Paper 49, p. 95, 1906.

Many coals (see p. 12) that have the appearance and some that have the physical properties of cannel coal do not have the same high volatile content or low fuel ratio. The cannel coal that is so extensively mined at Cannel City, Ky., for example, has an average content of about 40 per cent of volatile matter and 50 per cent of fixed carbon, indicating a fuel ratio of about 1.25. Cannel coal mined at Cannelton, Ind., contains 28 to 35 per cent of volatile matter and 58 to 60 per cent of fixed carbon. The cannel coal of Armstrong County, Pa., contains 30 to 31 per cent of volatile matter and 46 to 49 per cent of fixed carbon.

The low content of volatile matter in Pennsylvania cannels may be due to the loss of volatile matter by the pressure to which the rocks in that field have been subjected. This probability is perhaps best shown by comparing the proportion of volatile matter and fixed carbon in coal taken from benches of the same bed at points across the State in a line from west to east. First are given analyses from the lean or semicannel and bituminous parts of a bed in Armstrong County near the center of the western coal field of the State; next are given analyses from the Blossburg field of Tioga County, where the coal is of semibituminous rank; then from the Barclay field in Bradford County, the next county to the east; and last from the semianthracite field of Bernice, Sullivan County.

Changes in benches of Pennsylvania coal undergoing loss of volatile matter.

Location.	Canneloid bench.				Bituminous or semibituminous bench.			
	Volatile matter.	Fixed carbon.	Ash.	Fuel ratio.	Volatile matter.	Fixed carbon.	Ash.	Fuel ratio.
Southeast of New Salem, Armstrong County [a]	37.8	53.1	6.7	1:1.40	37.9	52.7	6.7	1:1.39
Fall Brook, Tioga County [b]	17.1	66.2	14.9	1:3.86	20.8	70.8	6.5	1:3.40
Barclay, Bradford County [c]	15.0	71.3	12.1	1:4.74	17.0	75.9	5.4	1:4.44
Bernice, Sullivan County [d]	9.0	63.7	24.6	1:7.06	9.6	82.3	5.5	1:8.64

[a] McCreath, A. S., Third report of progress in the laboratory of the Survey at Harrisburg: Pennsylvania Second Geol. Survey Rept. M3, p. 57, 1881.
[b] McCreath, A. S., Second report of progress in the laboratory of the Survey at Harrisburg: Pennsylvania Second Geol. Survey Rept. M2, p. 79, 1879.
[c] Idem, p. 80.
[d] Idem, p. 82.

David White[1] has recently called attention to the fact that petroleum does not occur in rocks near a bed of coal containing 65 per cent or more of fixed carbon, having apparently been driven off by heat and pressure. The fact that the semicannel coals from Armstrong County lie east of the oil field of Pennsylvania indicates that the action which restricted the Pennsylvania oil field also made semicannel of cannel coals. As these semibituminous and semianthracite canneloid coals from Tioga County eastward have so little in common with the true cannels in commercial use, they are not further considered in this report.

The semicannel coals of the Mississippi Valley States, such as those in Kentucky, lie so close to cannel coals high in volatile matter as to lead to the belief that the two may have had a very different origin. Thus, at Cannel City, Ky., in a single hill, there are two coal beds, one a typical cannel containing 52 per cent of volatile matter and 36 per cent of fixed carbon and the other, which is mined mainly as cannel, containing only 40 per cent of volatile matter and 50 per cent of fixed carbon. The cause of this difference has not yet been determined.

ANALYSES.

ANALYSES OF CANNEL COAL.

The tables which follow give, first, a few recent proximate and ultimate analyses of cannel coals that were properly sampled; next a few earlier ultimate analyses; next, for reference, a large number of earlier proximate analyses, many of which represent averaged samples, though some have been made from selected coal or hand

[1] White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, p. 212, 1915.

specimens rather than from the average commercial product. The ash in most of these analyses is probably lower than in the commercial coal, but the analyses are of value as indicating the richness of the coal in volatile matter, and the ash, as determined in many of them, is probably not far from that of the commercial coal.

Practically all the earlier analyses of cannels were made of air-dried coal that had been shipped to the laboratory in bags or boxes rather than in air-tight metal or glass receptacles, such as are commonly used to-day. As all the coals of the Appalachian field, however, carry small percentages of moisture, the air-drying loss in most of the samples has been very small. Moisture has, however, not been included in most of the tables.

Proximate and ultimate analyses of cannel and subcannel coals.[a]

No. of analysis.	Locality and bed.	Laboratory No.	Kind.[b]	Condition.[c]	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Air drying loss.	Calories.	British thermal units.
	JOHNSON COUNTY, KY.															
1	Flambeau, southeast of, 400 yards up mountain side, Flambeau mine, cannel bed, on chain pillar (150 feet southeast of opening, main entry 1, 18-inch cut).	7133	A	1	2.3	48.4	38.7	10.4	1.20	6.47	71.98	1.16	8.70	1.5	7,650	13,770
				2		49.5	39.6	10.7	1.23	6.36	73.72	1.19	6.76		7,835	14,100
				3		55.5	44.4		1.38	7.13	82.59	1.33	7.57		8,780	15,800
2	Same, 250 feet southeast of opening, entry 5, 51½-inch cut.	7132	A	1	2.2	50.6	36.7	10.4	.99	6.57	72.01	1.17	8.80	1.3	7,640	13,750
				2		51.7	37.5	10.7	1.01	6.47	73.63	1.20	6.99		7,810	14,060
				3		57.9	42.0		1.13	7.25	82.45	1.34	7.83		8,750	15,730
3	Lesley (East Point post office), Lesley mine, Lesley bed, cannel coal.	5437	A	1	1.7	50.7	38.2	9.3	1.02	6.83	73.25	1.31	8.28	.4	7,950	14,260
				2		51.6	38.8	9.4	1.04	6.75	74.52	1.33	6.89		8,050	14,500
				3		57.0	42.9		1.15	7.46	82.31	1.47	7.61		8,900	16,010
	KANE COUNTY, UTAH.															
4	Glendale, 13 miles northwest of, NE. ¼ sec. 26, T. 39 S., R. 9 W., on North Fork Virgin River, Cannel King prospect, 66-inch bench, upper 2 feet (subcannel).	5306	B	1	15.7	41.9	28.0	14.3	1.32	6.11	51.96	1.16	25.11	4.5	5,280	9,510
				2		49.7	33.2	17.0	1.57	5.17	61.67	1.38	13.19		6,270	11,280
				3		59.9	40.0		1.89	6.23	74.32	1.66	15.90		7,555	13,600
5	Same, lower 3½ feet	5308	B	1	7.3	46.9	22.4	23.2	1.61	6.18	51.88	1.06	16.03	1.1	5,733	10,380
				2		50.6	24.2	25.0	1.74	5.79	56.00	1.14	10.25		6,210	11,800
				3		67.6	32.3		2.32	7.73	74.75	1.52	13.68		8,290	14,920

[a] Lord, N. W., and others, Analyses of coals: Bur. Mines Bull. 22, pp. 105, 194, 1913.
[b] A, Mine sample collected by an inspector of the Geological Survey; B, mine sample collected by a geologist of the Survey.
[c] 1, Sample as received; 2, dried at temperature of 105° C.; 3, moisture and ash free.

Additional ultimate analyses of cannel coal.

No. of analysis.	Locality.	Condition.[a]	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Moisture.
6	Boghead, Scotland [b]	1a	18.6	0.15	9.1	65.3	0.7	5.4	......
	.....do	3	....	....	11.2	80.4	.8	6.7	......
7	Breckinridge, Ky.[b]	1a	14.8	2.4	6.4	68	2.2	5.3	......
	.....do	3	....	....	7.8	82.3	2.7	7.0	......
8	Haddock, Owsley County, Ky.[c]	1a	3.0	.2	6.1	76.7	13	7.	......
9	Albertite, Nova Scotia [d]	1a	.1	Tr.	9.2	85.4	3.0	2.2	......
10	English cannel, Nova Scotia [e]	1a	2.4	....	5.7	78.9	11	7	1.2
	.....do	3	....	....	5.9	81.9	....	12.1	......
11	Scotch cannel, Nova Scotia [e]	1a	12.0	1.4	9.7	70.5	3	0	3.2
	.....do	3	....	1.6	11.5	83.2	3	5	......
12	Wigan cannel, England [f]	3	....	1.4	6.08	79.2	1.1	7.2	......

[a] 1a, As received, probably crudely air dried; 3, moisture and ash free.
[b] Peter, Robert, Second chemical report of the ores, rocks, soils, coals, etc., of Kentucky: Kentucky Geol. Survey Second Rept., p. 213, 1857.
[c] Idem, p. 255.
[d] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 23, New York, Baillière Bros., 1865.
[e] Owen, D. D., Kentucky Geol. Survey Second Rept., p. 57, 1857.
[f] Idem, p. 59.

Analyses of Arkansas Camden coal (typical of brown subcannel).

No. of analysis.	Locality.	Analyst.	Condition.[a]	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
									Inches.
13	Brown mine [b]	G. Steiger.	A	38.7	36.9	16.9	7.5	0.5	42
14	.....do.[c]	...do	B	11.2	44.0	33.6	11.0	.7	42
15	Sec. 12, T. 13 S., R. 18 W.[b]	...do	A	38.0	37.1	79.9	5.8	.4	....
16	.....do.[c]	...do	B	11.0	47.9	32.8	8.2	.5	....
17	Sec. 10, T. 12 S., R. 18 W.[b]	...do	A	32.7	32.9	23.3	11.3	.4	....
18	.....do.[c]	...do	B	9.5	46.2	29.4	14.4	.6	....

[a] A, Analysis of fresh sample; B, analysis of sample after long drying.
[b] Taff, J. A., Preliminary report on the Camden coal field of southwestern Arkansas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 326, 1900.
[c] Idem, p. 327.

Proximate analyses of cannel coal.

No. of analysis.	Map No. in State.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		INDIANA.								
		DAVIESS COUNTY.								*In.*
19	1	Cannelburg [a]	2b	McTaggart and Cowder.	......	49.0	26.3	23.1	1.4	......
20	1	.....do. [a] [b]	2b	E. T. Cox	......	48.5	42.0	6.0	1.0	......
		PARKE COUNTY.								
21	......	Bethany [b]	2b	.....do	......	47.0	43.0	4.5	......	......
		PERRY COUNTY.								
22	2	Cannelton, middle part [b]	2c	.....do	......	43.0	48.5	2.0	......	......
23	2	Cannelton, Rock Island mine.[c]	2c	.....do	......	42.0	45.5	6.0	......	......

[a] Ashley, G. H., The coal deposits of Indiana: Indiana Dept. Geology and Nat. Res. Twenty-third Ann. Rept., pp. 988, 989, 1570, 1899.
[b] Cox, E. T., Indiana Geol. Survey Third and Fourth Ann. Repts., p. 187, 1872.
[c] Idem, p. 183.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		ILLINOIS.								
		M'LEAN COUNTY.								*In.*
24	......	Colfax [a]	2b	......	......	41.2	30.2	25.7	......	6
25	......	.....do. [a]	2b	......	......	30.9	30.3	39.6	......	10
		LA SALLE COUNTY.								
26	......	La Salle, Matthiessen mine. [a]	2b	......	......	39.7	33.6	23.3	......	......
		IOWA.								
		WEBSTER COUNTY.								
27	......	Kalo [b]	2c	......	......	39.0	39.2	15.8	7.12	......
		GUTHRIE COUNTY.								
28	......	Reese [c]	2b	......	......	30.8	28.2	36.0	11.0	......
		KENTUCKY.								
		BELL COUNTY.								
31	1	Steward Creek [d]	2a	......	......	52.2	25.1	17.8	2.9	18
32	2	Chenoa, Bear Creek [e]	2b	......	......	51.6	40.4	7.0	.7	45
33	3	Dorton Branch of Straight Creek. [f]	2c	......	1.25	40.9	55.1	2.0	......	......
		BREATHITT COUNTY.								
34	1	Troublesome Creek, mouth. [g]	2b	R. Peter	1.26	47.0	44.4	7.3	1.5	0-36
35	1	Troublesome Creek, Haddix mine. [h]	2b	Consolidated Gas Co., N. Y.	......	60.6	30.4	9.0	......	0-36
36	1	Troublesome Creek, Haddix mine. [i]	2b	R. Peter	1.21	48.9	47.0	3.0	.2	0-36
37	1	.....do	2b	.....do	1.21	46.6	46.8	5.0	.8	0-36
38	1	Troublesome Creek, Hargis mine. [j]	2b	T. Egleston	......	48.2	44.2	4.7	.7	......
39	1	Troublesome Creek [k]	2b	R. Peter	......	57.0	36.5	5.5	......	......
40	2	Troublesome Creek, Noble Branch. [l]	2b	......	......	50.9	36.7	11.7	......	......
41	3	Troublesome Creek, Fugitt Branch. [m] [n]	2c	R. Peter	1.28	43.4	46.9	6.2	.6	......
42	4	Georges Branch, Columbian Exposition. [o]	2a	J. S. Corry	......	64.6	29.2	4.0	.8	......
43	4	Georges Branch; sampler, P. N. Moore. [p]	2b	R. Peter	1.28	52.3	35.5	11.1	1.4	......

[a] Grout, F. F., Cannel coal in northern Illinois: Illinois State Geol. Survey Bull. 4, p. 198, 1907.
[b] Keyes, C. R., Coal deposits of Iowa: Iowa Geol. Survey, vol. 2, p. 509, 1894.
[c] Idem, p. 505.
[d] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 148, 1894.
[e] Crandall, A. R., and Sullivan, G. M., Report on the coal field adjacent to Pineville Gap in Bell and Knox counties: Kentucky Geol. Survey Bull. 14, p. 20, 1912.
[f] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 224, 1856.
[g] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 219, 1884.
[h] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 132, 1894.
[i] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 27, 1910.
[j] Hodge, J. M., Preliminary report on the geology of parts of Letcher, Harlan, Leslie, Perry, and Breathitt counties, p. 52a, Kentucky Geol. Survey, 1887.
[k] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 212, 1856.
[l] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 28, 1910.
[m] Peter, Robert, op. cit., p. 221.
[n] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 45, 1910.
[o] Hendrie, Charles, op. cit., p. 137.
[p] Peter, Robert, op. cit., p. 220.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		KENTUCKY—Contd.								
		BREATHITT COUNTY—con.								*In.*
44	4	Georges Branch; sampler, C. Hendrie.[a] [b]	2b	R. Peter	......	58.0	34.0	7.4	1.0	......
45	4	Georges Branch [c]	2b	Consolidated Gas Co., N. Y.	......	61.9	33.7	4.4	......	......
46	4	Georges Branch; sampler, T. Egleston.[d] [b]	2b	T. Egleston	......	45.4	40.1	12.8	1.7	......
47	4	Georges Branch, carload lot.[e]	2b	......	......	54.0	34.4	10.9	......	......
48	5	North Fork Kentucky River, Wolf Creek.[b] [f]	2b	......	......	41.7	33.3	24.2	......	......
49	6	Quicksand Creek, Roundbottom.[g]	2b	......	1.27	44.0	39.9	15.4	.4	37
50	7	Nichols Fork, Frozen Creek.[h]	2b	R. Peter	1.36	58.8	35.3	4.7	......	......
51	7	.....do.[h] [i]	2b	.....do	1.36	43.2	33.8	21.4	2.5	......
52	6-9	Quicksand Creek [d]	2b	T. Egleston	......	44.2	43.4	9.8	1.2	......
53	10-12	Quicksand Creek; sampler, J. R. Proctor.[j]	2c	R. Peter	1.32	43.1	43.3	11.4	4.6	......
54	12	South Fork Quicksand Creek, lower mine.[d]	2c	T. Egleston	......	39.4	48.2	9.5	1.2	......
54a	12	South Fork Quicksand Creek, upper mine.[d]	2c	.....do	......	45.6	47.1	4.9	1.7	......
55	13	Jackson, near [k]	2b	R. Peter	1.21	56.7	38.1	4.9	1.5	36
56	13	.....do.[l] [m]	2a	Consolidated Gas Co., N. Y.	......	68.0	28.2	3.8	......	10-16
57	14	Stacy Branch of South Quicksand Creek.[d] [n]	2a	T. Egleston	......	66.2	29.7	3.6	......	......
58	14	.....do.[o] [p]	2a	R. Peter	......	66.2	29.7	3.6	......	21
58a	14	.....do.[p]	2a	T. Egleston	......	62.4	31.4	6.0	......	21
59	20	Beginning Branch [q]	2c	R. Peter	1.27	41.1	46.7	11.2	1.2	18
60	22	Cockerill Fork [r]	2b	.....do	......	50.6	36.7	11.3	......	......
61	19	John Little Branch [q]	2b	.....do	1.17	53.8	39.5	5.3	.7	11
		CARTER COUNTY.								
62	1	Stinson Creek, Tarkiln Branch.[s]	2a	R. Peter	1.14	64.1	27.0	7.9	2.8	......
63	1	Stinson Creek, Stinson mine.[t]	2a	.....do	1.20	66.3	28.3	4.8	1.3	......
64	1	Stinson Creek [u]	2b	.....do	1.21	57.0	34.5	6.5	......	......
65	4	Barrett Creek [v]	2c	.....do	1.44	33.5	42.7	19.8	7.9	......
66	5	Little Sandy River, 6 miles south of Leon.[w]	2a	Dr. Stebbins	......	61.1	30.3	7.6	......	......
67	5	.....do	2b	Consolidated Gas Co., N. Y.	......	58.7	34.5	5.9	......	......
68	......	Crawford cannel, near Grayson.[x]	2b	R. Peter	1.21	57.0	34.5	6.5	......	......
		CLAY COUNTY.								
69	2	Toms Branch [q]	2b	R. Peter	1.16	44.1	43.7	11.8	1.2	5
70	3	Beech Creek [q]	2c	.....do	......	32.3	35.2	32.0	6.0	15

[a] Hendrie, Charles, op. cit., p. 135.
[b] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 71, 1910.
[c] Hendrie, Charles, op. cit., p. 136.
[d] Hodge, J. M., Preliminary report on the geology of parts of Letcher, Harlan, Leslie, Perry, and Breathitt counties, p. 52a, Kentucky Geol. Survey, 1887.
[e] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 65, 1910.
[f] Hodge, J. M., Kentucky Geol. Survey Bull. 11, pp. 65, 71, 1910.
[g] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 95, 1861.
[h] Crandall, A. R., op. cit., p. 64.
[i] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 219, 1884.
[j] Idem, p. 220.
[k] Owen, D. D., Kentucky Geol. Survey Bull. 10, p. 96, 1861.
[l] Hendrie, Charles, op. cit., p. 143.
[m] Fohs, F. H., Kentucky Geol. Survey Bull. 18, p. 35, 1912.
[n] Idem, p. 30.
[o] Hendrie, Charles, op. cit., p. 142.
[p] Fohs, F. H., op. cit., p. 77.
[q] Hodge, J. M., Preliminary report on the geology of the lower North Fork, Middle and South forks Kentucky River, Kentucky Geol. Survey, 1887.
[r] Hendrie, Charles, op. cit., p. 139.
[s] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 114, 1861.
[t] Idem, p. 111.
[u] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 201, 1856.
[v] Idem, p. 270.
[w] Hendrie, Charles, op. cit., p. 147.
[x] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 69, 1856.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		KENTUCKY—Contd.								
		GREENUP COUNTY.								*In.*
71	1	Hunnewell [a] [b]	2b	Peter and Talbutt.	1.30	52.2	40.6	5.7	0.7	......
72	2	Fulton Forge [c]	2c	R. Peter	......	40.2	52.4	2.7	.8	58
73	2	Chinns Branch [d]	2c	.....do	1.33	36.9	51.2	7.1	3.9	54
74	2	Indian Run [d]	2b	.....do	......	47.3	38.2	12.4	1.5	24
		HANCOCK COUNTY.								
75	1	Breckinridge cannel [e] [f]	2a	R. Peter and Talbott.	1.21	59.6	27.0	12.1	1.8	22-28
76	1	.....do.[g]	2b	R. Peter	1.31	34.4	32.0	12.1	......	22-28
77	1	.....do.[g] [h]	2a	.....do	1.33	62.4	28.2	7.9	......	22-28
78	1	Breckinridge cannel, average of 4 samples.[g]	2a	D. D. Owen	......	61.4	30.0	8.0	......	22-28
79	1	Breckinridge cannel, average sample. [i]	2a	R. Peter	......	59.6	27.0	12.1	1.9	22-28
80	1	Breckinridge cannel [j]	2a	Gesner	......	61.3	30.0	8.0	Tr.	22-28
		HARLAN COUNTY.								
81	......	Long Branch of Martin Fork.[k]	2c	R. Peter	1.51	34.6	39.4	24.6	1.2	38
82	3	Sharps Branch of Yokum.[l]	2c	.....do	......	21.8	29.6	47.4	5.4	15
83	15	John Branch of Catron [m].	2b	A. S. McCreath	......	47.9	32.2	17.7	.8	33
84	......	Head of Catron [m]	2b	.....do	......	42.8	35.4	20.1	.5	22
85	14	Catron, opposite mouth of John Branch.[n]	2c	.....do	......	40.6	47.9	7.9	2.3	40
86	14	.....do.[n]	2c	R. Peter	......	37.3	54.9	7.0	1.9	40
		JACKSON COUNTY.								
87	3	Coyle mine, 17 miles southeast of Richmond.[o]	2c	R. Peter	1.33	41.0	43.1	13.9	1.0	21
88	4	Branch of Horse Lick [o]	2c	.....do	1.32	43.6	45.5	8.7	3.3	9
		JOHNSON COUNTY.								
89	1	Whitehouse [p]	2c	......	......	41.8	46.0	11.0	.9	......
89a	1	.....do.[q]	2c	R. Peter	......	40.2	51.0	8.8	.9	......
90	3	Twomile Creek [r]	2b	......	......	53.6	39.6	5.1	.8	......
91	4	East Point [r]	2b	......	......	55.0	36.2	6.3	.9	......
92	4	.....do.[s]	2b	N. W. Lord	......	51.6	38.8	9.4	1.0	69
93	9	Flambeau [s]	2b	.....do	......	49.5	39.6	10.7	1.2	......
94	9	.....do.[s]	2b	.....do	......	51.7	37.5	10.7	1.0	......
		KNOTT COUNTY.								
95	1	Trace Fork of Soto Creek [t]	2c	......	1.25	44.1	49.4	6.0	.7	......
96	2	Wolfpen Branch of Little Carr Creek. [u] [v]	2b	......	......	47.9	44.8	6.9	.7	......

[a] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 167, 1884.
[b] Norwood, C. J., A report on the reconnaissance of a part of the Breckinridge cannel-coal district: Kentucky Geol. Survey Repts. on western coal field, D, p. 217 [25], 1884.
[c] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 171, 1861.
[d] Crandall, A. R., Report on the Chinns Branch cannel-coal district: Kentucky Geol. Survey Repts. on eastern coal field, C, p. 6 [200], 1884.
[e] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 65, 1910.
[f] Peter, Robert, op. cit., p. 83.
[g] Norwood, C. J., Kentucky Inspector of Mines Tenth Ann. Rept., p. 13, 1894.
[h] Idem, p. 177.
[i] Idem, p. 14.
[j] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 51, New York, Baillière Bros., 1865.
[k] Peter, Robert, op. cit., p. 265.
[l] Hodge, J. M., The upper Cumberland coal field: Kentucky Geol. Survey Bull. 13, p. 51, 1912.
[m] Ashley, G. H., and Glenn, L. C., Geology and mineral resources of part of Cumberland Gap coal field, Ky.: U. S. Geol. Survey Prof. Paper 49, p. 201, 1906.
[n] Idem, p. 198.
[o] Peter, Robert, op. cit., p. 273.
[p] Crandall, A. R., The coals of the Big Sandy Valley: Kentucky Geol. Survey Bull. 4, p. 28, 1905.
[q] MacFarlane, Graham, Notes on American cannel coal: Am. Inst. Min. Eng. Trans., vol. 18, p. 438, 1890.
[r] Crandall, A. R., op. cit., p. 35.
[s] Lord, N. W., and others, Analyses of coals in the United States: Bur. Mines Bull. 22, pt. 1, p. 105. 1913.
[t] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 93, 1910.
[u] Crandall, A. R., Report on the Pound Gap region, p. 29, Kentucky Geol. Survey, 1887.
[v] Hodge, J. M., op. cit., p. 107.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		KENTUCKY—Contd.								
		KNOX COUNTY.								
										In.
97	3	Road Fork, 7 miles from mouth.[a]	2c	A. M. Peter	......	41.3	46.8	10.5	1.5	41
		LAWRENCE COUNTY.								
98	1	Torchlight, Threemile Creek.[b]	2b	....	......	54.9	39.3	2.9	.5	......
99	1	.....do.[b]	2c	S. R. Hislop	......	45.6	47.1	3.9	.6	......
		LESLIE COUNTY.								
100	2	Laurel Fork Cutskin Creek.[c d]	2c	R. Peter	1.25	45.3	47.2	6.9	.6	23
101	2	.....do.[c d]	2b	A. M. Peter	1.22	46.9	45.1	6.3	.7	23
102	3	Oldhouse Branch of Beech Fork.[e]	2b	R. Peter	......	44.2	43.7	11.0	.6	38
		LETCHER COUNTY.								
103	1	Line Fork of Defeated Creek.[f]	2c	A. M. Peter	1.43	34.0	39.1	25.8	.5	......
104	3	Millstone Branch of Rockhouse Creek.[g]	2b	.....do	1.30	46.1	40.5	13.0	2.0	......
105	......	Defeated Creek[h]	2c	A. S. McCreath	......	40.4	42.0	16.4	.4	36
106	6	Mill Branch of Rockhouse Creek.[i]	2c	R. Peter	1.30	39.3	51.8	6.9	1.1	10
		M'LEAN COUNTY.								
107	......	Sent in by H. C. Jarvis[j]	2b	A. M. Peter	......	42.9	35.4	20.6	.6	......
		MAGOFFIN COUNTY.								
108	......	Greasy Creek[k]	2b	S. R. Hislop	1.19	52.6	41.1	5.4	......	......
109	3	Saylersville[l]	2b	R. Peter	......	45.6	43.4	9.2	.6	14
110	4	Colvin Mine[l m]	2b	.....do	......	51.9	37.5	8.2	1.4	36
		MORGAN COUNTY.								
111	2	Mordecai Creek[l]	2b	R. Peter	......	39.3	38.8	18.0	1.1	36
112	3	Rush Creek[l]	2b	.....do	......	44.0	38.8	15.5	.9	58
113	......	Worth Fork, Adkins[l]	2b	.....do	......	42.4	33.7	19.5	1.5	40
114	......	Elk Fork, Maynheir mine.[l n]	2c	.....do	1.33	41.6	44.7	11.4	1.2	26
115	9	Pierat, Maytown[l n]	2b	.....do	1.23	49.6	43.2	5.1	.9	36
116	8	Cannelton, Caney Fork of Licking River.[o]	2c	.....do	......	40.0	51.0	8.4	.5	22½

[a] Crandall, A. R., and Sullivan, G. M., Report on the coal field adjacent to Pineville Gap in Bell and Knox counties: Kentucky Geol. Survey Bull. 14, p. 125, 1912.
[b] Phalen, W. C., Economic geology of the Kenova quadrangle: U. S. Geol. Survey Bull. 349, p. 59, 1908.
[c] Hodge, J. M., Preliminary report on the geology of parts of Letcher, Harlan, Leslie, Perry, and Breathitt counties, p. 48, Kentucky Geol. Survey, 1887.
[d] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 196, 1910.
[e] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 222, 1910.
[f] Idem, p. 127.
[g] Idem, p. 135.
[h] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 144, 1894.
[i] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 146, 1910.
[j] Stone, G. W., Kentucky Inspector of Mines Sixteenth Ann. Rept., p. 115, 1900.
[k] Idem, p. 114.
[l] Crandall, A. R., Preliminary report on the geology of Morgan, Johnson, Magoffin, and Floyd counties: Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [1880].
[m] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 18, 1910.
[n] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 296, 1884.
[o] Crandall, A. R., Kentucky Geol. Survey Bull. 10, p. 14, 1910.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		KENTUCKY—Contd.								
		MORGAN COUNTY—con.								*In.*
117	13	Brush Fork Caney Creek (Lykins)[a].	2c	R. Peter		41.0	45.1	12.0	0.8	25
118		Sugar Camp Branch Caney Creek.[a]	2c	....do		41.6	49.1	8.5	1.6	25½
119		Old House Branch Caney Creek.[a]	2c	....do		40.8	48.8	8.6	.8	24
120	6	Spring Branch Caney Creek (drift 11).[a]	2c	....do		40.4	48.8	9	2.7	28½
121		Johnson Branch Prater Fork Caney Creek.[a]	2c	....do		40.6	50.2	7	1.2	21
122		Sugar Camp Branch Caney Creek (drift 1).[a]	2c	....do		40.7	51.2	6	.7	
123		Caney Creek (drillings)[a].	2c	....do		37.9	49.6	10	1.0	
124	7	Benton Branch Yearling Branch.[a]	2b	....do		52.3	36.4	10	.7	22
		OWSLEY COUNTY.								
125		South Fork Kentucky River, 4 miles above Booneville.[b]	2b	R. Peter	1.16	59.7	32.3	7.4		
126		South Fork Kentucky River, Merrill mine.[c]	2b	....do		47.6	46.3	5.4		
127		South Fork Kentucky River, Reynolds mine.[d]	2b	....do		55.0	34.7	9.7		
128		South Fork Kentucky River.[e]	2b	Consolidated Gas Co., N. Y.		52.6	43.6	3.8		
129		....do	2b	....do		53.3	43.2	3.5		
130		Haddock, between South and Middle Fork Kentucky River.[f]	2b	R. Peter		48.9	47.0	3.0	.2	
		PERRY COUNTY.								
131	1	Lots Creek[g]	2c	R. Peter	1.25	44.1	49.4	6.0	.7	22
132		Middle Fork, below Rush Branch.[h]	2c	....do		44.8	54.4	16.8	.9	10
		PIKE COUNTY.								
133		Bear Fork Robinson Creek.[i]	2c	R. Peter	1.29	43.4	46.3	8.3	.6	33
		WHITLEY COUNTY.								
134		Patterson Creek, Polly mine, whole bed.[j]	2c	R. Peter		39.7	55.0	3.0	.8	52
135		Patterson Creek, Polly mine, cannel only.[k]	2c	A. S. McCreath		47.1	52.2	1.2	1.1	31
136		Patterson Creek, head of[l].	2c	H. M. Curry		43.9	54.8	1.2	.6	24–31
137		Little Caney[j]	2c	R. Peter		43.0	48.8	7.2	1.2	28
138		Halsey[m]	2c	Perkins & Co.		48.0	49.5	2.5		

[a] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 14, 1910.
[b] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A., pt. 1, p. 315, 1884.
[c] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 144, 1894.
[d] Idem, p. 143.
[e] Idem, p. 145.
[f] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 355, 1856.
[g] Hodge, J. M., Preliminary report on the geology of parts of Letcher, Harlan, Leslie, Perry, and Breathitt counties, p. 48, Kentucky Geol. Survey, 1887.
[h] Hodge, J. M., Preliminary report on the geology of the lower North Fork, Middle and South forks Kentucky River, p. 96, Kentucky Geol. Survey, 1887.
[i] Crandall, A. R., Report on the Pound Gap region, p. 29, Kentucky Geol. Survey, 1887.
[j] Crandall, A. R., Report on the geology of Whitley County and a part of Pulaski, p. 38, Kentucky Geol. Survey, 1889.
[k] Hendrie, Charles, op. cit., p. 148.
[l] Idem, p. 147.
[m] Stone, G. W., Kentucky Inspector of Mines Sixteenth Ann. Rept., p. 115, 1900.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		KENTUCKY—Contd.								
		WOLFE COUNTY.								In.
139	......	Gilmore Creek, Ely's [a]	2b	R. Peter	1.43	41.4	28.2	29.1	0.8	......
140	......	Stillwater Creek [a]	2b	.....do	1.38	44.5	32.7	21.5	.5	......
		OHIO.								
		COSHOCTON COUNTY.								
141	4	Bedford cannel [b]	2b		......	47.0	37.0	1.8	......	......
142	4	Bedford cannel, Taylor mine. [c]	2c	T. G. Wormley	1.29	36.8	43.2	19.9	1.3	......
		HOLMES COUNTY.								
143	3	Near Nashville [d]	2c	T. G. Wormley	......	40.5	49.5	5.6	1.5	36
144	3	Strawbridge mine [e]	2c	.....do	......	28.6	52.7	16.5	2.1	96
145	3	3 miles northeast of Millersburg. [e]	2b	.....do	1.29	41.6	41.2	15.9	1.5	24
146	3	Strawbridge mine [c]	2c	.....do	1.39	37.3	44.6	16.3	1.7	......
147	3	Gloscen mine [c]	2c	.....do	1.29	40.5	49.9	5.6	1.5	......
148	3	.....do	2b	.....do	1.38	44.7	42.9	9.9	2.5	......
		JACKSON COUNTY.								
149	7	Milton Township [b]	2b		......	44.5	41.1	12.0	......	......
150	7	Gillard mine [c]	2c	T. G. Wormley	1.27	37.7	51.7	6.2	1.2	......
151	7	Sells mine [c]	2c	.....do	1.29	38.4	50.0	5.2	1.2	......
		LICKING COUNTY.								
152	5	Flint Ridge, selected [b]	2b		......	43.8	43.7	8.6	......	......
153	5	Flint Ridge, average [b]	2b		......	43.0	42.6	11.1	......	......
154	5	Flint Ridge [c]	2c	T. G. Wormley	1.29	36.8	43.2	19.9	1.3	......
155	5	.....do	2c	.....do	1.43	40.2	44.0	13.2	1.3	......
		MAHONING COUNTY.								
156	1	Canfield, Wetmore mine, top. [f]	2c	T. G. Wormley	......	33.5	45.6	19.1	2.6	60
157	1	Canfield, Wetmore mine, bottom. [f]	2c	.....do	......	40.6	46.2	11.5	2.0	60
		STARK COUNTY.								
158	......	"Canton cannel" [c]	2c	T. G. Wormley	1.20	31.4	59.5	6.0	3.0	......
		TRUMBULL COUNTY.								
159	......	Liberty Township [b]	2b		......	49.2	38.0	10.2	......	......
		PENNSYLVANIA.								
		ARMSTRONG COUNTY.								
160	9	South of New Bethlehem, Bostonia. [g]	2c	A. S. McCreath	......	30.4	46.1	22.2	.5	0-108
161	......	South of New Bethlehem [g]	2c	.....do	......	31.6	49.8	17.3	.4	......
162	8	Cathcart Run, No. 1 mine. [h]	2c	.....do	......	32.6	52.3	13.3	1.0	......
163	7	Little Mudlick Creek, No. 3 mine. [h] [i] [j]	2c	.....do	......	37.8	53.1	6.7	.6	......

[a] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, p. 328, 1884.
[b] Ashley, G. H., Cannel coal in the United States: Min. World, vol. 23, p. 382, Oct. 7, 1905.
[c] Newberry, J. S., Ohio Geol. Survey Rept. Progress for 1870, p. 420, 1871.
[d] Idem, p. 33.
[e] Idem, p. 31.
[f] Idem, p. 36.
[g] Platt, Franklin, Report of progress in the Clearfield and Jefferson district: Pennsylvania Second Geol. Survey Rept. H, p. 240, 1875.
[h] Platt, W. G., Report of progress in Armstrong County: Pennsylvania Second Geol. Survey Rept. H5, p. 180, 1880.
[i] Butts, Charles, Economic geology of the Kittanning and Rural Valley quadrangles, Pa.: U. S. Geol. Survey Bull. 279, p. 99, 1906.
[j] McCreath, A. S., Third report of progress on the laboratory of the Survey at Harrisburg: Pennsylvania Second Geol. Survey Rept. M3, p. 57, 1881.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		PENNSYLVANIA—Con.								
		BEAVER COUNTY.								
										In.
164	11	Cannelton [a]	2b	A. S. McCreath		48.0	38.2	11.9	0.5	60-192
165	11	.....do. [b]	2b			58.0	32.2	7.9	.5	60-192
		INDIANA COUNTY.								
166	5	South of Richmond, near top.[c]	2c	A. S. McCreath		23.3	50.3	24.8	.6	99
167	5	South of Richmond, near center.[c]	2c	.....do.		24.4	52.9	21.0	.6	99
		TENNESSEE.								
		CAMPBELL COUNTY.								
167a	1	Newcomb [d]	2b			49.8	35.0	15.1	.7	0-36
		TEXAS.								
		WEBB COUNTY.								
168		Rio Grande Coal & Irrigation Co., upper bench.[e]	2b?	P. Fireman		48.6	36.1	12.9		14
169		Rio Grande Coal & Irrigation Co., lower bench.[e]	2b?	.....do.		45.6	39.9	11.7		14
170		Cannel Coal Co., upper bench.[f]	2b?	.....do.		49.9	37.5	9.7		30
171		Cannel Coal Co., upper part of lower bench.[f]	2b?	.....do.		48.3	33.1	16.5		6
172		Cannel Coal Co., lower part of lower bench.[f]	2b	.....do.		49.3	38.0	10.2		11
173		Santa Tomas mine [f]	2b?			51.0	39.0	7.3	1.5	
174		25 miles northwest of Santa Tomas.[f]	2b?			42.6	37.5	16.5	.8	
		UTAH.								
175		Colob field, Virgin River, upper 2 feet.[g]	1b			41.9	28.0	14.3	1.3	24
176		Colob field, Virgin River, lower 3½ feet.[g]	1b			46.9	22.4	23.2	1.6	42
		WEST VIRGINIA.								
		BOONE COUNTY.								
177	9	Head of Mud River [h]	2b	Hite and Krak		50.9	35.8	12.7	1.1	44
178	9	.....do.[i]	2c	Paul Dember		40.6	51.1	6.2	.6	44
179	11	Head of Rucker Branch • Little Coal River.[j]	2b	Hite and Krak		49.3	36.1	13.8	1.5	18
180	12	Head of Workman's Branch, Pond Fork.[i]	2b	Paul Dember		51.8	34.3	12.9	1.0	50
181	13	Pond Fork below Robinson Fork.[k]	2b	Hite and Patton		47.3	40.2	11.7	1.4	
182	17	Pond Fork [h]	2c	.....do.		38.16	53.47	7.2	1.7	38

[a] McCreath, A. S., Second report of progress on the laboratory of the Survey at Harrisburg: Pennsylvania Second Geol. Survey Rept. M2, p. 54, 1879.
[b] Mansfield, I. F., Fire clays, coals, and titles of the cannel-coal tract at Cannelton, Beaver County, Pa., p. 9, 1905.
[c] Platt, W. G., Report of progress in Indiana County: Pennsylvania Second Geol. Survey Rept. H4, p. 230, 1878.
[d] MacFarlane, Graham, Notes on American cannel coal: Am. Inst. Min. Eng. Trans., vol. 18, p. 438, 1890.
[e] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, p. 64, 1900.
[f] Idem, p. 65.
[g] Richardson, G. B., The Harmony, Colob, and Kanab coal fields, southern Utah: U. S. Geol. Survey Bull. 341, p. 397, 1900.
[h] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., p. 575, 1915.
[i] Idem, p. 324.
[j] Idem, p. 576.
[k] White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2 (A), p. 399, 1908.

Proximate analyses of cannel coal—Continued.

No. of analysis.	Map No. in county.	Locality.	Classification (See p. 10).	Analyst.	Specific gravity.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Thickness of bed.
		WEST VIRGINIA—Con.								
		KANAWHA COUNTY.								*In.*
183	1	Queen Shoals Coal Co., Mine No. 1.[a]	2c	Hite and Patton	......	39.3	46.0	13.9	0.8	......
184	3	Villa Coal Mining Co., Villa.[b]	2b	.....do	......	45.3	43.7	10.3	1.5	53
184a	6	Cannelton [c]	2c		......	43.1	49.5	7.4	1.1	0-36
185	7	Lackawanna Coal & Lime Co., Wacomah mine, Paint Creek.[d]	2c	.....do	......	41.3	46.2	12.1	.5	17½
186	11	Little Barrier Creek [e]	2b	J. B. Krak	......	36.56	36.1	26.1	.4	36
		PRESTON COUNTY.								
187	1	Left Fork of Sandy Creek, Marquies.[f]	2c	Hite and Krak	......	23.9	45.3	30	.6	15
		LINCOLN COUNTY.								
187a	1	John Smith mine, near Jenks.[g]	2c	Krak and Hite	......	39.7	54.1	5.3	1.2	......
187b	2	Scites mine, near Jenks [g]	2c	.....do	......	44.2	49.9	5.0	.9	......
		GREAT BRITAIN.								
......	......	English cannel coal [h]	2c	R. Peter	......	42.4	54.0	2.4	......	......
......	......	Scotch cannel coal [h]	2b	.....do	......	42.7	42.1	12	......	......
......	......	Lesmahago, Scotland [i]	?		......	[j]44.6	41.3	9.1	......	......
......	......	.....do.[i]	?		......	[j]49.3	40.9	6.3	......	......
......	......	Lesmahago cannel, Scotland.[k]	2b	Miller	1.26	56.7	37.2	6.0	1.14	......
......	......	Wayness cannel coal [k]	?		......	[j]58.52	25.2	14.2	......	......
......	......	Wigan cannel coal [k]	?		......	[j]37.0	60.0	3.0	......	......
......	......	Wigan cannel, England [l]	2c	Vaux	1.27	39.6	57.6	2.7	1.5	......
......	......	Boghead cannel, Scotland.[m]	2a		......	70.1	10.3	19.6	......	......
......	......	Torbanite, Scotland [l]	2a	H. How	1.17	71.1	7.6	21.1	.7	......

[a] Krebs, C. E., and Teets, D. D., Kanawha County: West Virginia Geol. Survey County Repts., p. 439, 1914.
[b] Idem, p. 453.
[c] MacFarlane, Graham, Notes on American cannel coal: Am. Inst. Min. Eng. Trans., vol. 18, p. 483, 1890.
[d] Krebs, C. E., and Teets, D. D., op. cit., p. 485.
[e] Idem, p. 421.
[f] Hennen, R. J., and Reger, D. B., Preston County: West Virginia Geol. Survey County Repts., p. 364, 1914.
[g] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., p. 404, 1915.
[h] Owen, D. D., Kentucky Geol. Survey Second Rept., p. 56, 1857.
[i] Idem, p. 58.
[j] Includes moisture.
[k] Idem, p. 59.
[l] Ells, R. W., Joint report on the bituminous or oil shales of New Brunswick; also, on the oil-shale industry of Scotland; pt. 2, Geology, p. 33, Canada Dept. Mines, Mines Branch, 1909.
[m] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, p. 48, 1865.

ANALYSES OF ASH.

In order to round out the groups of analyses the analyses of the ash of a number of cannel coals are given in the following table:

Analyses of ash of cannel coals.

	Silica.	Alumina, oxides of iron, and manganese.	Lime.	Magnesia.	Phosphoric acid.	Sulphuric acid.	Potash and soda.	Percentage of ash in sample.
Boghead, Carter County, Ky.[a]	1.88	1.68	0.27	0.63	....	0.30	0.29	5.07
Boghead, Carter County, Ky. (lower 18 inches)[b]	2.78	4.2	.55	.30	....	....	....	7.87
Roundbottom, Quicksand Creek, Breathitt County, Ky.[c]	11.58	2.98	.21	.24	Tr.	.10	.28	15.40
South mine, near Jackson, Breathitt County, Ky.[d]	1.5	1.98	.41	.20	Tr.	.24	.48	4.90
Breckinridge cannel, Hancock County, Ky.[e]	3.49	7.78	.53	.39	....	....	....	12.21

[a] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 111, 1861.
[b] Idem, p. 114.
[c] Idem, p. 95.
[d] Idem, p. 96.
[e] Peter, Robert, Second chemical report of the ores, rocks, soils, coals, etc., of Kentucky: Kentucky Geol. Survey Second Rept., p. 211, 1857.

ANALYSES OF OCCLUDED GAS.

No figures were obtained showing the results of dissolving out such parts of cannel coal as would be acted on by pyridine or other solvents. Clarke,[1] however, quotes from the results of an investigation by Thomas in the extraction of gases in vacuo at 100° from a number of coals, including some cannels. From his results the following figures have been selected:

Analyses of gases from cannel and other coals.

	1	2	3	4	5	6	7	8
Carbon dioxide (CO_2)	6.44	9.05	53.94	84.55	68.75	36.42	18.90	14.72
Methane (CH_4)	80.69	77.19	....	....	....	....	67.47	84.18
Ethane (C_2H_6)	4.75	7.80	....	....	2.67	....	....	....
Propane (C_3H_8)	....	....	....	.91	....	....	....	....
Oxygen (O_2)	....	....	....	....	....	.80	1.02	....
Nitrogen (N_2)	8.12	5.96	46.06	14.54	28.58	62.78	12.61	1.10
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Amount of gas...cubic centimeters	421.3	350.6	16.8	55.7	55.7	55.9	147.4	600.6

1, 2. Wigan cannel.
3. Scotch cannel, Wilsontown.
4. Scotch cannel, Lesmahago.
5. Cannel shale, Lasswade, near Edinburg.
6. Bituminous coal.
7. Steam coal.
8. Anthracite coal.

The differences here are so striking that they are probably accidental and are due to differences in the time of exposure of the coal in mines and during its removal to the laboratory.

[1] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, p. 758, 1916.

IGNITING POINT.

The igniting point of cannel coal is given by Lewes[1] as 668° F. or 370° C., as compared with 842° F. or 430° C. for lignite, and 870° F. or 477° C. for Welsh steam coal. As is well known, the name cannel comes from candle, the early name of the coal, employed because of the readiness with which a splinter of it ignites and burns "like a candle."

ORIGIN.

More than 50 years ago Newberry[2] recognized the fact that cannel coals have the nature of water-laid deposits. According to White and Thiessen[3] the microscopic study of cannel coals shows that they include fern spores, water weeds, algae, and other material that naturally accumulates in the open water of swamps. The remains of certain water animals—fish, mollusks, amphibians, and crustaceans—are in places associated in abundance with cannel coals. Finally, in many places cannel coal grades over into bituminous shale or ordinary shale. In a cut on the Indiana Southern Railroad near Burn City, Daviess County, Ind., a bed of cannel coal, a foot or two thick, grades upward into coal which is similar in appearance, but which, on burning, leaves about half its original bulk as ash, and still higher into material which, though it resembles cannel, is reported by those who have tested it in a stove to leave a volume of ash greater than that of the coal put in. Above that bed the black color gradually turns to gray, and at the top there is only an ordinary gray clay shale. In some areas cannel coal grades into shale horizontally.

The close relation of cannel to shale is also seen in the high ash content of many cannels, due to the washing in of mud during the formation of the coal. Mud washed into an open-water basin tends to accumulate most abundantly at the point of entrance, and cannel forming in such a basin may be quite free of ash in one part and be high in ash in another part.

That the material of cannel coal has been formed by the settling of floating material and not from plants grown in place is further indicated by the fact that cannel coal, unlike bituminous coal, which is generally underlain by a bed of clay containing the roots of plants, in many if not in most places rests on rocks other than clay.

Again, although bituminous coal usually shows distinct banding, supposed to be due to changing surface conditions in the coal marsh, cannel coal is homogeneous, as if the conditions remained constant during the whole period of its deposition.

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[1] Lewes, V. B., The carbonization of coal, etc., p. 22, 1912.

[2] Newberry, J. S., On the mode of formation of cannel coal: Am. Jour. Sci., 2d ser., vol. 23, p. 212, 1857.

[3] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, 1913.

Furthermore, Newberry[1] has called attention to the fact that in lagoons of open water found near modern peat marshes a fine carbonaceous mud accumulates that, when properly dried, resembles cannel coal in appearance and in many properties.

Many theories have been advanced to account in detail for the formation of cannel coal. According to the theory here stated, it was formed at the bottom of open-water basins or small channels, most of them in coal-forming swamps (as indicated by the almost universal association of cannel with bituminous coal), by a steady accumulation of plant spores, pollen, resins, waxes, and other carbonaceous material. The source of the large percentage of volatile hydrocarbons, especially ethylene gas, which it yields on distillation, remains to be determined. Possibly these hydrocarbons were formed by the decomposition of the inner parts of the spores, having been held in temporary storage within the tough fine-grained spore cases. No study has been made, to the writer's knowledge, of this particular question, though distillation tests have been made on spore dust mixed with fuller's earth. One test reported by Ells,[2] the conditions of which are not known, yielded 23.8 gallons of crude oil (specific gravity, 0.93) and 3.3 pounds of sulphate of ammonia per ton.

MODE OF OCCURRENCE.

GENERAL FEATURES.

Too much stress can not be put on the fact that cannel coal occurs in very small basins. Thousands of dollars have been wasted in expensive preliminary equipment for mining deposits of cannel coal which proved to contain less than a year's supply. Long railroad spurs, one as much as 12 miles in length, have been built and expensive plants have been erected on the favorable showing presented by a single opening. A cannel-coal basin should therefore be prospected as thoroughly as a gold lode. It should be tested not by drilling every 10 acres but by drilling every acre. Where the coal lies high in the hills it may be sufficiently prospected by drillings or openings 100 yards apart. The fact that thick cannel is found at two points a quarter of a mile apart is no guaranty that it is thick between those points.

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[1] Newberry, J. S., Ohio Geol. Survey Rept., vol. 2, pt. 1, p. 125, 1874.

[2] Ells, R. W., Joint report on the bituminous or oil shales of New Brunswick; also on the oil-shale industry of Scotland; pt. 2, Geology, p. 69, Canada Dept. Mines, Mines Branch, 1909.

The mode of occurrence of cannel coal may best be understood from the description of two or three typical basins. (See fig. 1.)

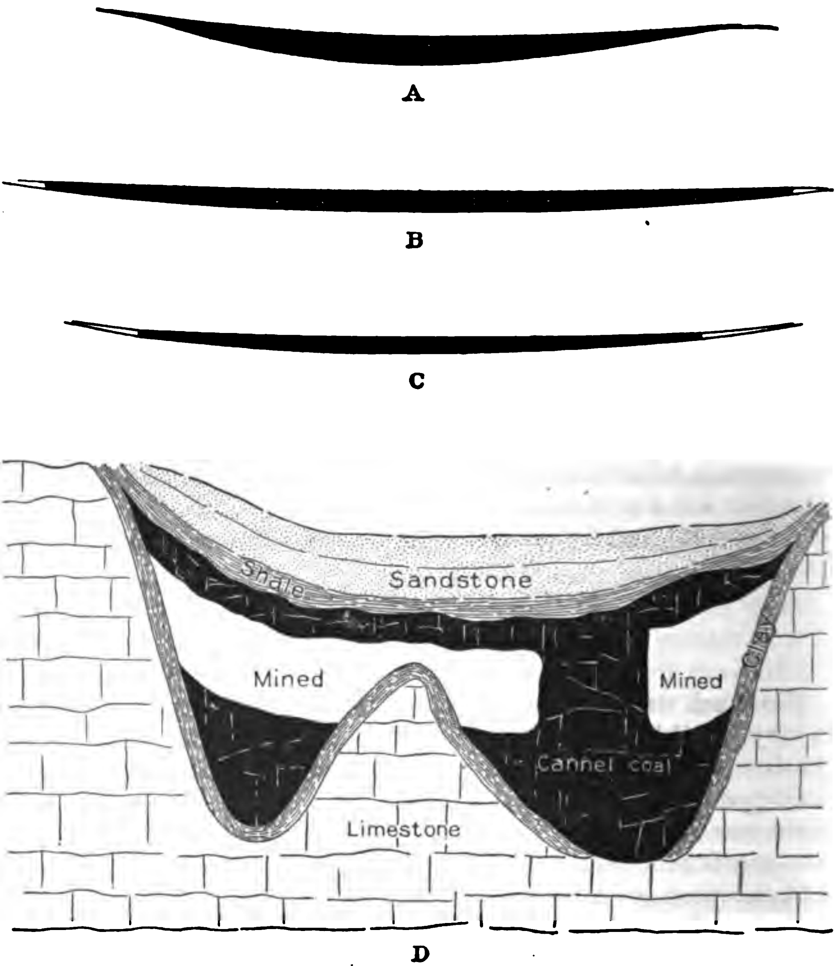


FIGURE 1.—Cross section of cannel-coal basins. A, Cross section of cannel-coal bed at Cannelton, Beaver County, Pa.; B, cross section of cannel-coal basin south of New Bethlehem, in Armstrong County, Pa.; C, cross section of cannel-coal basin on Bear Run, Bell County, Ky.; D, cross section of cannel-coal basin through an erosion channel in lower Carboniferous limestone in Cooper County, Mo.

DEPOSIT AT CANNELTON, PA.

The deposit of cannel coal at Cannelton, Beaver County, Pa., occupies a 600-foot channel whose course suggests that it lies in an abandoned oxbow or horseshoe circumscribing a basin 2 miles long by 1 mile wide. Along the center of the channel the cannel coal has a thickness of 15 feet or more, and is underlain by 1 foot of bituminous

coal. About 150 feet from each side of the axis of the channel the cannel bench has decreased in thickness to 5 feet and the bench of bituminous coal has in places thickened to 2 feet, the bottom of the cannel coal apparently grading into the upper foot of bituminous coal. Within this width of 300 feet the form of the channel is indicated by slight dips toward its axis. Beyond that width the bottom of the channel rises sharply to 20 to 27 feet above the level of the center of the channel and both cannel and bituminous coal thin gradually down to nothing. Over the cannel coal in the center of the channel lies a heavy body of bituminous shale, almost as rich in yield of oil as the cannel coal itself. (See Pl. IV, *A*.)

The cannel coal here is, as usual, distinctly a block coal, being cut by nearly vertical joints or "slips," most commonly 4 feet apart, along which the coal commonly breaks up into blocks about 4 by 4 feet, though in places the joints are as little as 1 foot apart. As usual in block coal the "face slips" or joints continue unbroken for long distances, and the "butt slips" break and offset somewhat in crossing the face slips. Where examined the face slips ran S. 70° E., or nearly at right angles to the axis of the basin. In passing from the axis of the basin to the edges the butt slips may be observed to lean toward the axis at the top. At one point where measured this lean amounted to 12°. It was reported by Mr. Mansfield, the owner, that the face slips maintain a constant direction entirely around the oval. As the angle between this constant direction of the slips and the changing direction of the axis of the channel changes in coming about the oval basin, this leaning disappears but reappears on the other side of the oval, where the face slips are again at right angles to the axis of the channel.

DEPOSITS AT BOSTONIA, PA.

The cannel coal in the center of the channel of the coal basin at Bostonia, Armstrong County, Pa. (see fig. 1, B, and fig. 3, p. 59), has a thickness of 9 feet and is underlain by 18 inches of bituminous coal. Coal has been worked from this central axis for a maximum distance of 300 to 400 feet on either side, in which distance the bottom of the basin rises 8 to 10 feet above the bottom of the channel at its axis and the coal decreases in thickness to the minimum that can now be profitably mined. Under more favorable conditions mining could doubtless be pushed a little farther outward from the central axis. This channel, which can be followed for a number of miles (see p. 60) from a point northwest of Bostonia through the surface ridge to the southeast and then eastward, is uniform neither in depth nor width, nor in the character of its coal, which is not everywhere

cannel. Like most cannel-coal basins it resembles a lagoon rather than a channel cut by running water.

DEPOSIT AT CHENOA, KY.

The cannel-coal channel at Chenoa, Bell County, Ky., is similar to the others just described. The coal in the center of the basin is thick, but within 400 feet on either side it decreases in thickness to the minimum that can be profitably mined. (See fig. 1, C.)

Cannel-coal basins of somewhat different type occur in Missouri, where most of the coal lies in basins eroded in the underlying limestone. One basin (fig. 1, D) about 100 feet wide and of undetermined length, has been followed 500 feet in east and west. The total depth of the coal is more than 70 feet.

Hinds[1] has described these Missouri pockets as follows:

> Pockets are in one sense only outliers but may be distinguished by certain unique features. Briefly stated, they are shale, coal, sandstone, and clay deposits laid down in sink holes or small depressions and surrounded by walls of limestone belonging to Mississippian and older formations. They occur in nearly all parts of the State outside the main Pennsylvanian body and are especially numerous in Lincoln, Callaway, Cooper, Cole, Morgan, Moniteau, and southwestern counties. They are round or elliptical in horizontal cross section, are commonly only a few hundred feet in width, and are in many cases as deep as they are wide. Many contain as much as 30 to 90 feet of coal, chiefly of the cannel variety, and have excited much comment. In most cases the component layers are saucer shaped, dipping inward on all sides from the surrounding limestone walls as though the entire mass had slipped down a considerable distance. Fractures and slickensides indicate that part of this slipping occurred after the consolidation of the materials, though many of the coal pockets probably sank during deposition, the action of the humic acids hastening the deepening of the sinks. Sinks that were deepened in this way while sediments were accumulating were probably slightly above ground-water level at that time. Deposition in many sinks probably took place after the drainage outlets at their bases had been choked up as a result of a slight subsidence of the region in which they lie. Some of the shale and sandstone deposits may have been formed after the region was invaded by the continental sea, though this is not necessarily the case. Certainly those containing coal were deposited while the region was free from brackish or salt waters. It is probable that solution was renewed at the bottoms of the sinks whenever ground-water level was lowered as a result of post-Pennsylvanian regional movements and that many of the deposits are still sinking.

USES.

HEATING.

High-grade cannel coal is adapted to most of the common uses of other bituminous coals except the making of coke. As it burns freely, it was used in the early days in the manufacture of iron. It

[1] Hinds, Henry, and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 13, pp. 41–42, 1915.

A.

B.

CANNEL COAL MINING, PAST AND PRESENT.

is an ideal grate fuel and has long been used for that purpose, for it mines out in blocks, is clean to handle, and gives a bright, cheerful blaze, resembling that of a wood fire. It differs from wood, however, in containing only a small percentage of moisture, for wood is 50 per cent water, so that it does not require constant replenishing and makes a fire that can be left overnight. Where grates are the principal means of heating houses the special advantages of cannel coal are readily apparent.

Owing to the large percentage of gas it contains cannel coal ignites quickly and is useful where a hot fire is needed in a hurry. It has long been a satisfactory fuel for fire engines and during recent years has found one of its principal markets in city fire departments.

GAS MAKING.

For many years cannel coal was most largely used for enriching coal gas. Cannel coal does not make a good coke and is not so cheap as other bituminous coals, or its large content of gas of high candlepower would undoubtedly cause it to be used for the manufacture of coal gas to the exclusion of all other coals. The so-called "gas coals" contain 30 to 40 per cent of volatile matter, whereas the better grade of cannel coal contains 50 to 60 per cent, and its gas has double the illuminating power of that in the gas coals. Thus Hocking Valley coal will yield about 8,000 cubic feet of 14-candlepower gas and Westmoreland coal about 10,000 feet of 15 to 16 candlepower gas per ton of coal. By contrast, Flint Ridge, Ohio, cannel will yield 9,000 feet of 23-candlepower gas per ton; Kanawha, W. Va., cannel will yield 10,000 feet of 18 to 19 candlepower; richer cannels will yield from 13,000 to 15,000 cubic feet of 30 to 40 or even 50 candlepower; and according to McMillin[1] some of the special bituminous substances will yield as high as 131 candlepower. According to Stone[2] the candlepower of the gas from some of the better-known cannel coals is as follows:

Candlepower of gas from cannel coals.

Breckinridge, Ky	46.2
Georges Branch, Ky	31.1
Chenoa, Ky	41.2
Boghead, Ky	38.1
Hunnewell, Ky	35.1
Pineville, Ky	44.55
Falling Rock, W. Va	36.1
Lesmahago, Scotland	34.5
Boghead, Scotland	38.2
New Battle, Scotland	35.3

[1] McMillin, Emerson, The gas coals of Ohio: Ohio Geol. Survey Rept., vol. 5, Economic geology, pp. 722–749, 1884.

[2] Stone, G. W., Kentucky Inspector of Mines Sixteenth Ann. Rept., p. 112, 1900.

As most cities require gas of a higher candlepower than could be obtained from bituminous gas coals alone, it has been necessary to enrich the product by adding to it some gas of higher candlepower, and for many years cannel coal found its principal market for this purpose. Later, cheaper methods, especially the addition or substitution of oil-enriched water gas, were widely adopted, and to-day little or no cannel coal is used for this purpose.

Future demand may again lead to the distillation of cannel coal at high temperatures in order to obtain certain products or by-products. For that reason, as well as for the purpose of showing its behavior when so treated and the compounds it yields, the following data have been assembled:

The percentage of "volatile combustible matter" shown by analysis is not a true index of the amount of fixed gas that may be obtained in practice. Thus, by a series of tests, Wormley[1] obtained (among other results) from coals yielding 27.7, 30.7, 37.2, 38.0, and 39.2 per cent of volatile matter on analysis, 3.32, 3.51, 3.12, 3.65, and 3.35 cubic feet, respectively, of fixed gas per pound of coal. The temperature at which gas is made also affects greatly both the quantity and quality of the gas—the higher the temperature the greater the quantity of gas and the lower the candlepower. Experiment has shown a marked difference in the composition of gas derived from cannel coal and that derived from the bituminous gas coals, as is clearly indicated by the difference in the candlepower of the two gases. This difference consists principally in the smaller percentage of uncombined hydrogen and the larger percentage of olefines, especially ethylene, in cannel gas.

It is due, no doubt, to the abundance of ethylene that cannel coal gas has so high an illuminating value. Though unable to find, at the time of writing, analyses of the volatile matter from cannel coal, the writer recalls analyses in which the percentage of ethylene, for example, was several times as high as in gas from bituminous coal reported in the same table. Ethylene (C_2H_4) is what is called an unsaturated hydrocarbon—that is, one having the formula C_nH_{2n} rather than the formula C_nH_{2n+2}. As a result, in burning, it first breaks up into methane, or marsh gas (CH_4), setting free carbon, which is next heated to incandescence, yielding the light, and then burned to CO_2. The significance of the greater percentage of ethylene may be appreciated from the following table given by Lewes:[2]

[1] Wormley, T. G., Report of chemical department: Ohio Geol. Survey Rept. Progress for 1870, pt. 5, p. 410, 1871.

[2] Lewes, V. B., The carbonization of coal, p. 286, 1912.

Heating value and candlepower of gases derived from coal.

	British thermal units, gross per cubic foot.	Candle-power per 5 cubic feet.
Hydrogen	325	0
Methane	1,024	5.2
Ethane	1,870	35.0
Propane	2,682	53.3
Ethylene	1,603	70.0
Benzene	3,718	820.0
Carbon monoxide	342	0

The following table gives the results of tests made to show the quality of gas produced from a number of cannel coals and, for comparison, the results of similar tests of a few bituminous coals. Most of the reports quoted do not indicate whether the long or the short ton is the unit employed, but the long ton (2,240 pounds) is probably the one used in nearly if not quite all of them. Trustworthy comparisons are afforded only by tests reported by the same analyst, for there has been no universal standard for such tests and the results of comparisons between tests made under different conditions are not reliable:

Quantity and quality of gas produced by cannel coals and some gas coals.

	Gas per long ton.	Candle-power.	Analyst.
SCOTLAND.			
	Cubic feet.		
Lesmahago [a]	13,201	34.5	Hislop, G. R.
Bathville Boghead [a]	14,690	42.66	Do.
Tyne Boghead [a]	13,155	38.2	Do.
Newbattle [a]	12,461	35.3	Do.
PENNSYLVANIA.			
Pittsburgh coal, Rend mines [b]	11,200	15	Columbus Gas Co., Ohio.
Youghiogheny gas coal [b]	10,300	17	Do.
Washington County, bituminous [c]	9,880-10,120	16.1-8.3	Pittsburgh Testing Laboratory (Ltd.).
Beaver County, cannel [c]	10,160	22.5	Do.
Pittsburgh gas coal [c]	9,500-10,000	16	Do.
OHIO.			
Hocking Valley [d]	8,960	15	Columbus Gas Co., Ohio.
Sterling [e]	11,782	18.8	Prof. Chandler.
Flint Ridge [d]	10,080	24	Columbus Gas Co., Ohio.

[a] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 154, 1894.

[b] McMillin, Emerson, The gas coals of Ohio: Ohio Geol. Survey Rept., vol. 5, Economic geology, p. 735, 1884.

[c] Taff, J. A., Preliminary report on the Camden coal field of southwestern Arkansas: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 2, p. 329, 1900.

[d] McMillin, Emerson, op. cit., p. 733.

[e] Edwards, W. S., Coals and cokes of West Virginia, pp. 71-72, 1892.

Quantity and quality of gas produced by cannel coals and some gas coals—Contd.

	Gas per long ton.	Candle-power.	Analyst.
WEST VIRGINIA.			
	Cubic feet.		
Cabin Creek, gas [a]	11,460	18.7	Columbus Gas Co.
Do.[b]	14,200	17	Cincinnati Gas Co., Ohio.
Do.[b]	14,000	19	Consolidated Gas Co., N. Y.
Cannelton, cannel [b]	11,200	64.5	Manhattan Gas Co., N. Y.
Peytona, cannel [b]	14,780	42.7	Do.
Do [b]	13,660	45.6	Do.
Falling Rock, cannel [c]	14,210	36.1	Hislop, G. R.
Grahamite [d]	13,500	28	
KENTUCKY.			
Bear Creek [e]	14,630	41.2	Hislop, G. R.
Pineville:			
Boghead [e]	15,805	36.2	Do.
Willaford [e]	15,835	44.5	Do.
Boghead, Carter County [e]	14,752	38.1	Do.
Hunnewell, Greenup County [e]	14,260	35.1	Do.
Georges Branch [e]	13,300	31.1	Do.
Breckinridge [e]	15,200	46.2	
Greasy Creek, Johnson County [f]	14,130	40.1	Do.
Halsey, Whitley County [g]	14,560	22.7	Knoxville Gas Co., Tenn.
Poplar Lick bed, Log Mountains [h]	12,230	22.1	Hislop, G. R.
Cannel [i]	12,540	30.5	Pittsburgh Testing Laboratory (Ltd.).
NOVA SCOTIA.			
Albertite [d]	13,200	49	
ARKANSAS.			
Camden lignite [i]	11,386	22.3	Pittsburgh Testing Laboratory (Ltd.).

[a] McMillin, Emerson, op. cit., p. 736.
[b] Edwards, W. S., Coals and cokes of West Virginia, pp. 71-72, 1892.
[c] Stone, G. W., Kentucky Inspector of Mines Sixteenth Ann. Rept., p. 112, 1900.
[d] McMillin, Emerson, op. cit., p. 725.
[e] Hendrie, Charles, op. cit., p. 150.
[f] Stone, G. W., op. cit., p. 114.
[g] Idem, p. 115.
[h] Idem, p. 117.
[i] Taff, J. A., Preliminary report on the Camden coal field of southwestern Arkansas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 329, 1900.

In order that the possible differences in the volumes of gas and the candlepower, due to different temperatures of distillation, may be fully realized in later tables the variation in the volume of gas and tar and in the composition of the gas resulting from the distillation of coal at different temperatures is given below.

Yield of gas and tar per ton of coal carbonized.[a]

Temperature of distillation.		Volume of gas.	Tar.	Specific gravity of tar.
°C.	°F.			
		Cubic feet.	*Gallons.*	
900	1,652	11,000	9	1.200
800	1,472	10,000	12	1.170
700	1,292	9,000	15	1.140
600	1,112	7,750	18	1.115
500	932	6,400	21	1.087
400	752	5,000	23	1.060

[a] Lewes, V. B., The carbonization of coal, p. 162, 1912.

The figures given are stated to be "average results."

Effect of temperature of carbonization on the percentages of the chief constituents of the gas.[a]

Temperature		400	500	600	700	800	900
	°C.	400	500	600	700	800	900
	°F.	752	932	1,112	1,292	1,472	1,652
Hydrogen		21.2	28.3	33.8	41.6	48.2	54.5
Saturated hydrocarbons		60.1	56.2	50.7	45.0	39.1	34.2
Unsaturated hydrocarbons		6.3	5.8	5.0	4.4	3.8	3.5

[a] Lewes, V. B., The carbonization of coal, p. 163, 1912.

The difference in candlepower resulting from different temperatures of distillation was well shown in experiments by L. T. Wright (quoted by the Encyclopedia Britannica) on four portions of the same coal heated to different temperatures.

Yield and candlepower of gas distilled at different temperatures.

	Gas per ton.	Illuminating power per 5 cubic feet of gas.	Total illuminating power per ton.
	Cubic feet.	*Candles.*	*Candles.*
1. Dull red	8,250	20.5	33,950
2. Hotter	9,693	17.8	34,510
3. Hotter	10,821	16.7	36,140
4. Bright orange	12,006	15.6	37,460

On this subject see further, for American coals, the work of Porter and Ovitz [1] and Parr and Francis.[2] The results were summarized by Vignon,[3] as follows:

1. Imperfect hydrocarbons (C_2H_2, C_2H_4, C_6H_6) distill chiefly at temperatures below 600° and disappear at high temperatures.

2. Methane and carbide are very abundant (60 to 84 per cent) up to 800° and then decrease rapidly with temperature.

3. Hydrogen comes off in small quantities (2 to 20 per cent) up to 600°, greatly predominates from 800 to 1,000°, and then sometimes decreases from this temperature up to 1,200°.

4. CO, which ranges from 3 to 11 per cent and averages 6.5 per cent up to 850°, may exceed 30 per cent above 1,000°. Increasing temperature increases the quantity of gas; the gas obtained at 1,000° has low calorific value and, in general, contains considerable CO.

Detailed tests of some of the best Kentucky cannels have been made by G. R. Hislop, gas engineer of the Paisley Gas Works, Scotland.

[1] Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bur. Mines Bull. 1, 1910.
[2] Parr, S. W., and Francis, C. K., The modification of Illinois coal by low-temperature distillation: Illinois Univ. Eng. Exper. Sta. Bull. 24, 1908.
[3] Vignon, Leo, Fractional distillation of coal: Jour. Gas Lighting, vol. 121, p. 107, 1913.

Results of tests of Kentucky cannel and bituminous coals.

	Carter County, Boghead.[a]	Greenup County, Hunnewell.[a]	Bell County, Bear Creek.[b]	Poplar Lick seam.[b]	Mason (Mingo) seam.[b]	Lower lignite seam.[b]	Johnson County, Greasy Creek.[c]	Breathitt County, Georges Creek.[c]
Specific gravity	1.175	1.215					1.191	1.350
Chemical analyses (per cent):								
Moisture expelled at 212° F	1.21	2.75						
Volatile matter	54.92	47.23					0.75	
Fixed carbon	35.17	43.58					52.67	50.00
Ash	8.08	5.55					46.58	44.00
Sulphur	.62	.89						
Gaseous products:								
Gas per ton of coal at 60° F., 30 inches barometer . . cubic feet	14,752	14,260	14,630.00	12,230.00	11,895.00	12,520.00	14,130.00	13,303
Gas from 1 cubic foot of coal . . do	541.37	483.44	470.25	422.09	406.55	432.11		
Specific gravity of the gas (air 1,000)	700	644	745.00	510.00	514.00	512.00		
Hydrocarbons absorbed by bromine . . per cent	15.33	14.25	18.30	6.25	6.20	6.50		
Durability of 1 cubic foot by 5-inch jet flame . . minutes	72′ 4″	66′ 48″	78′ 45″	47′ 16″	46′ 51″	48′ 10″		
Value of 1 cubic foot of gas (sperms) . . grains	915.60	843.12	989.76	535.84	524.84	543.60		
Value of gas from 1 ton of coal (sperms) . . pounds	2,158.72	1,725.86					1,945.09	1,420
Illuminating power of gas . . standard candles	38.15	35.13	41.24	22.16	21.86	22.65	40.15	31.15
Sulphureted hydrogen (H_2S) in foul gas . . per cent	1.25	1.75	1.20	0.75	1.00	0.80	1.50	1.0
Carbon dioxide (CO_2) in foul gas . . do	2.50	2.50	1.80	2.00	1.75	2.20	2.00	2.8
Carbon monoxide (CO) in foul gas . . do	7.00	5.50	7.75	7.25	6.00	7.00	7.75	
Sulphur eliminated with volatile products . . pounds	9.85	12.09	9.18	6.04	7.63	6.04		
Liquid products:								
Tar per ton of coal . . gallons	20.34	20.12	26.68	15.22	15.81	16.80		
Ammoniacal liquor per ton of coal . . do	4.43	11.31	6.30	17.30	18.62	16.37		
Strength of ammoniacal liquor . . °Twad	4.00	3.00	5.00	2.75	2.75	2.75		
Hygrometric water per ton of coal . . gallons	2.71	6.16	3.40	9.99	9.74	12.32		
Aqueous absorbent capacity of coal (determined by complete saturation) . . per cent	1.35	2.80	1.75	5.50	5.25	5.36		
Solid products:								
Coke per ton of coal . . pounds	972.83	1,108.35	994.78	1,384.32	1,395.52	1,357.44	1,043.39	987
Carbon in the coke . . per cent	81.40	88.80	92.30	97.70	98.80	96.50	88.46	
Ash in the coke . . do	18.60	11.20	7.70	2.30	1.20	3.50	11.54	11.4
Sulphur in coke per ton of coal . . pounds	4.03	7.84	3.58	5.60	2.45	4.93		
Heating power of 1 pound of coke (water from boiling point into steam) . . pounds	11.18	12.20	12.68	13.42	13.57	13.25		

[a] Phalen, W. C., Economic geology of the Kenova quadrangle: U. S. Geol. Survey Bull. 349, p. 90, 1908.
[b] Ashley, G. H., and Glenn, L. C., Geology and mineral resources of part of Cumberland Gap coal field, Ky.: U. S. Geol. Survey Prof. Paper 49, p. 218, 1906.
[c] Hendrie, Charles, Some Kentucky cannels: Kentucky Insp. Mines Tenth Ann. Rept., p. 136, 1894.

The three bituminous coals in the above table are of gas-coal quality, having a percentage of volatile hydrocarbons above 35. Comparison between them and the cannel coals shows that the cannels yield a higher specific gravity, higher candlepower, and higher value per cubic foot in sperms. It also shows that the cannels yield more tar, though this is in a measure offset by their smaller yield of ammoniacal liquor. The bituminous coals, on the other hand, yield more and better coke.

Writing in 1893, Hendrie[1] describes some of the effects of substituting water gas for the gas formerly enriched with cannel coal:

The Consolidated Gas Co. of New York in former years used to use from 25,000 to 30,000 tons of cannel per annum for enriching purposes. They now use only a few thousand tons. This applies to all the large gas works in this country. On the other hand, the handling of large quantities of naphtha oil is attended with great risk and danger, especially in large cities, and a first-class cannel will always find a ready market at a certain price, and this to a great extent is governed by the question of transportation. There is a good market in South America, England, and portions of the Continent. The exhaustion of the English cannels is rapidly taking place, and Kentucky alone can take their place in any quantity. Toward the end of 1892 the city of London ceased to use cannel gas, an event marking an important epoch in the cannel trade. This was caused by the fact that about the only available cannel in quantity coming into this market—the Scotch Lesmahagow—cost 58 shillings per ton, delivered in the Thames. Sufficient quantity could not even be obtained at this price, and as ordinary coal will not yield 16 candlepower gas crude oil from Russia is employed to maintain the statutory power. By this means the gas companies in that city were able to furnish 16 candlepower gas at 3 shillings 1 pence per 1,000 cubic feet, as against 4 shillings 9 pence for cannel gas, a difference which the public were quick to appreciate and accede to. The large amount of gas now used for cooking purposes has also tended to lessen the demand for a gas of high illuminating power.

COKE MAKING.

It is well known that cannel coal will not make good coke. It belongs to the group of free-burning coals which do not intumesce or run together into a cake, and the coke made from it is, as a rule, pulverulent and soft, that made from some beds crumbling at once to powder. It would seem to be feasible to use this coke in the production of water gas or producer gas or for burning under furnaces as dust, but not in metallurgy nor for stove use.

OIL MAKING.

The use of cannel coal of most interest, both in the past and in the future, however, is in the production of oil and other chemical by-products. It was this use that led to its widespread mining from 1855 to 1859, when the discovery of petroleum opened the way to its

[1] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 149, 1894.

displacement, and it is this use that is apparently again calling attention to it, the oil now being demanded for conversion into the lighter hydrocarbons (especially gasoline) for use in portable motors and the by-product chemicals for the enlarging chemical industry of the country.

The use of coal for the production of oil is not recent, it having been employed for the purpose as early as 1760. In Lewis's Materia Medica, published in that year, mention is made of oils distilled from black bituminous shales for medical purposes. Even earlier than that, in 1694, patents were issued, according to Gesner,[1] to Eele, Hancock, and Portlock for making "pitch, tar, and oyle out of a kind of stone." In 1781 the Earl of Dundonald distilled oil from coal, and others distilled oils and tars from bituminous schists, so that at an early date these oils, somewhat purified, were used for burning in lamps and for lubricating machinery.

Abraham Gesner claims to have been the first to manufacture oil from coal in the United States, and in 1846 exhibited the use of his oil in lamps. His patents, known as the "kerosene patents," granted nine years later, were sold to the North American Kerosene Gaslight Co., which proceeded to make and sell "kerosene oil," as it was called. This early oil was not so highly refined as kerosene is to-day. and a disagreeable odor in burning kept down its sale. It came into common use about 1854. In the autumn of 1855 work was begun at Breckinridge, Ky., on an oil distillery, and by April, 1856, 12 retorts were in operation there, producing 600 to 700 gallons daily. In June, 1856, the Breckinridge Coal & Oil Co. consolidated with the Breckinridge Cannel Coal Co., and 18 more retorts were added.

The rapid extension in the refining of oil from cannel coal and other bituminous substances has been described by Baskerville,[2] as follows:

In 1853 the United States Chemical Manufacturing Co. began working coal tar for the manufacture of lubricating oil at Waltham, Mass., and in 1857 the Downer Kerosene Oil Co. first made mineral oils from Albert coal mined in New Brunswick. The large works of Downer, in Boston, were erected at a cost of half a million dollars; and at Portland, Me., Downer erected a smaller works for distilling imported coal. About this time the New Bedford Co., of New Bedford, Mass., commenced the distillation of Boghead coal, imported from Scotland, but later substituted domestic Breckinridge coal and West Virginia coal for the imported material.

In 1859 six plants were erected by various companies near Pittsburgh, Pa., and one of these (the Lucesco Co.) had a distilling capacity of 6,000 gallons of crude oil per day. This company had $120,000 invested in its works, and in 1860 ten large revolving retorts were in operation. Sixteen 2,000-gallon stills

[1] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 8, New York, Baillière Bros., 1865.

[2] Baskerville, Charles, Economic possibilities of American oil shales: Eng. and Min. Jour., vol. 88, p. 151, 1909.

were used in the refinery. Many of the companies in operation worked under licenses from the Young Co., of Scotland. In 1860 there were fifty-five coal-oil companies in existence in the United States. These were as follows:

Adair & Veedler, Pittsburgh, Pa.
Aladdin Co., Kiskiminitas, Pa.
Anderson Co., Darlington, Pa.
Atlantic Co., New York, N. Y.
Beloni & Co., New York, N. Y.
Boston & Portland Co., Boston, Mass.
Breckinridge Co., Cloverport, Ky.
Brooks Co., Zanesville, Ohio.
Carbon Co., New York, N. Y.
Cornell & Co., Canfield, Ohio.
Covington Co., Covington, Ky.
Cox Co., Zanesville, Ohio.
Dean Co., Cleveland, Ohio.
Downer Co., Boston, Mass.
East Cambridge Co., East Cambridge, Mass.
Empire State Co., New York, N. Y.
Enon Valley Co., Enon Valley, Pa.
Eureka Co., New York, N. Y.
Excelsior Co., New York, N. Y.
Falling Rock Co., Kanawha, Va. [now W. Va.].
Forest Hill Co., Kanawha, Va. [now W. Va.].
Franklin Co., New York, N. Y.
Glendon Co., Boston, Mass.
Grasseli Co., Cincinnati, Ohio.
Great Kanawha Co., Kanawha, Va. [now W. Va.].
Great Western Co., Newark, Ohio.
Greers Co., Kanawha, Va. [now W. Va.].
Hartford Co., Hartford, Conn.
Himebaugh & Co., Coshocton, Ohio.
Kerosene Co., New York, N. Y.
Knickerbocker Co., New York, N. Y.
Long Island Co., New York, N. Y.
Lucesco Co., Kiskiminitas, Pa.
New Bedford Co., New Bedford, Mass.
New York & Wheeling Co., Wheeling, W. Va.
New York Coal Oil Co., New Galilee, Pa.
North American Co.,Kiskiminitas, Pa.
Orion Co., New York, N. Y.
Page & Co., Boston, Mass.
Palestine Co., Palestine, Pa.
Peasley Co., Boston, Mass.
Phoenix Co., Cincinnati, Ohio.
Pictou Co., New York, N. Y.
Pinkham Co., Boston, Mass.
Preston Co., Virginia [now W. Va.].
Ritchie Co., Ritchie County, Va.
Robinson Co., Perry County, Ohio.
Sherwood Co., Canfield, Ohio.
Stamford Co., Stamford, Conn.
Staunton Co., Kanawha, Va. [now W. Va.].
Union Co., Maysville, Ky.
Western Co., Cincinnati, Ohio.
White-Day Co., Monongahela County, Va. [now W. Va.].
Zephyr Co., New York, N. Y.

Many of the above-mentioned companies were of small capacity, and most of them were not more than fairly started when the discovery of petroleum paralyzed the industry. The owners were threatened with considerable loss, from which they were rescued, however, by converting their oil works into petroleum refineries, this being accomplished with little outlay of time or money.

Modern methods of distilling cannel coal would doubtless follow in the main the methods now used in Scotland and Germany in the distillation of oil shale, described by Baskerville[1] and by Ells.[2] Baskerville has also described the methods in use in the United States when cannel coals were formerly distilled for oil.

[1] Baskerville, Charles, Economic possibilities of American oil shales: Eng. and Min. Jour., vol. 88, pp. 152–153, 1909.

[2] Ells, R. W., Joint report on the bituminous or oil-shales of New Brunswick; also, on the oil-shale industry of Scotland; part 1, Economics, pp. 13–14, Canada Dept. Mines, Mines Branch, 1910.

About 1860 two types of retorts were in use in the United States and Canada, viz, the horizontal D-shaped retorts and revolving retorts. The former were made of both iron and clay and were from 30 to 45 inches in width and 8 to 10 feet in length. A retort 10 feet in length was capable of distilling three charges of cannel coal of 450 pounds each in 24 hours at a heat not exceeding 415°. Two or three of these retorts were heated over one furnace, and often as many as forty discharged into a common main. The discharge pipes leading from the retorts to the main were about 8 inches in diameter, and they were inserted into the end of the retort opposite the head and the furnace. The main was generally 3 feet in diameter.

The revolving retorts were iron or clay cylinders, 6 feet in diameter and 8 feet in length, sustained upon an axle at each end, the vapors passing through the axle opposite the furnace. The cylinders were kept in motion by machinery and made two or three revolutions per minute. One of these retorts ran six charges of one ton each in 24 hours. In using this retort a saving of fuel was found, but they were more expensive and more liable to get out of order. Consequently the horizontal D-shaped retort was favored.

The largest stills for refining were about 8 feet 6 inches in diameter and 4 feet 6 inches in height. The condensing worms were about 100 feet in length, with a diameter of 6 inches where they left the necks and 4 inches throughout the middle parts, tapering down to 2 inches at the tail pipes. The oil was refined as follows: After the water had settled from the oil and had been drawn off, the crude oil was generally distilled in a common iron still. When the oil had been "run off" to four-fifths of the whole quantity, steam was let into the still, and frequently superheated steam was used.

The first distillate was separated into two parts, the first being that which distilled over from the commencement until the specific gravity reached 0.843. This oil, which constituted the lamp oil, was placed in an iron cistern and agitated from one to two hours with from 4 to 10 per cent of sulphuric acid, and then allowed to settle for eight hours. The oil was then washed with 10 to 20 per cent water and afterward with 5 to 10 per cent soda solution (specific gravity 1.40). After settling for six hours the oil was again washed with water and run into a still for final rectification. When the specific gravity reached 0.819 the distillation was stopped and the residue was transferred to the heavy oil.

The heavy oil was that portion of the crude oil which formed the second part of the first distillate. It was generally distilled off in steam to the end of the distillation. The heavy oils were purified in much the same manner as the lighter oils, excepting more acid and stronger alkali solutions were employed. The paraffin wax was crystallized from the heavy oil by exposing it in tanks in a cool place. The oil was pressed out from the wax, which was then purified by acid and alkalies, pressed, and finally cast in molds. Certain alterations of these general methods of retorting and refining were made in New Brunswick in 1864–65. Whether they were improvements or not, we are not able to ascertain.

DISTILLATION FOR BY-PRODUCTS.

The renewed interest in cannel coal is largely based on its supposed value as a source of what were formerly considered by-products in the manufacture of artificial gas, but which at present have be-

come of primary importance. The figures already given indicate clearly that certain lean or semicannel coals, though suitable for certain uses (as in household grates), have no advantage over bituminous coals in the production of gas or oil. The figures also show, however, that the higher-grade cannel coals yield a variable but always larger percentage of the coal gas, coal oil, and ammoniacal liquor, and it is hoped that some method may be found for obtaining benzol and its derivatives from these by hydrogenation.

Both the quantity and the quality of the products obtained by the destructive distillation of coal depend on the temperature and pressure and some other factors of the distillation. (See pp. 39 and 48.) If the temperature of distillation is 1,000° to 1,200° F. or more, a large volume of gas will be driven off and there will remain a small quantity of tar, from which the coal-tar products are derived, and a large quantity of coke, usually equivalent to more than one-half the weight of the coal. If, however, the temperature of distillation be kept below 800° F. the quantity of gas will be much reduced, the quantity of coke possibly a little increased, and a considerable volume of oil given off in place of the coal tar.

Munroe[1] has summarized by classes a few of nearly a thousand derivatives of the ammoniacal liquor and tar obtained in making coal gas. From the ammoniacal liquor are obtained ammonium carbonate, sulphide, polysulphide, chloride, cyanide, sulphocyanide, and other combinations, depending on the process employed. The coal tar yields the benzene series, including benzene, naphthalene, fluorene, phenanthrene, and anthracene; nitrogen-containing compounds, as aniline, the pyridines, the picrolines, quinolines, isoquinolines; sulphur compounds, as thiophene; and hydroxy compounds, as phenols and cresoles. From these substances are derived cleansing compounds, paints, and paint removers; dyestuffs, as the aniline dyes, synthetic alizarine, and indigo; antiseptics and germicides, as carbolic acid and the naphtholes; explosives, as picric acid and trotile; flavoring materials, as methyl, salycilate, and vanilline; perfumes, as geran oil and artificial musk; febrifuges, as antipyrene and acetanilid; sweetening principles, as saccharine; photographic developers, as hydroquinone; etc.

A number of cannel-coal samples obtained by the writer in Pennsylvania were subjected to dry distillation in 1914–15 under the direction of D. T. Day. A preliminary series of tests were made by J. A. Dorsey at the Geological Survey, and a second series by C. R. Bopp at the Bureau of Mines.

[1] Munroe, C. E., By-products in gas manufacture: Franklin Inst. Jour., vol. 174, p. 17, 1912.

Dry distillation tests of Pennsylvania cannel coals (1914–15).[a]

[By J. A. Dorsey and C. R. Bopp.]

Source.	First test.			Second test.				
	Coal used.	Oil.		Coal used.	Yield per short ton.			
		From sample.	Per short ton.		Oil.	Water.	Gas.	Ammonia.
Center County:	*Grains.*	*C. c.*	*Gals.*	*Oz.*	*Gals.*	*Gals.*	*Cu. ft.*	*Pounds.*
Lula mine	100	5	12.0	6	10.7	11.9	4,071	1.8
Clearfield County:								
Jury mine	100	5	12	6	14	7	4,467	2.39
Lansberry mine	100	5	12	6	10.5	7	4,467	5.14
Indiana County:								
Altoona mine	100	10	24	6	20.3	7.7	4,790	5.57
Armstrong County:								
Bostonia mine	100	17	40.8	6	33.6	7	5,029	5.37
Pine Run No. 1	100	14	33.6	6	25.2	9.8	5,029	5.06
Pine Run No. 3	100	8	19.2	6	31.5	8.4	4,311	3.68
Beaver County:								
Cannelton, coal	100	21	50.4	6	37.3	10.5	5,268	2.24
Cannelton, slate	100	12	28.8	6	27.3	9.1	2,905	.92

[a] Ashley, G. H., Oil resources of black shales of the eastern United States: U. S. Geol. Survey Bull. 641, p. 319, 1917.

In the following tests a thousand grains of coal were submitted to distillation by Peter, the heat being gradually raised to a dull red. The oil, ammonia, and coke were collected in a train of three tubulated receivers and the gas in a bell glass.

Tests of 1,000 grains of Kentucky cannels (1856–1859).

[By R. Peter.]

Source.	Gas.		Oil.	Ammoniacal water.	Coke.
Breathitt County:	*Grains.*	*Cu. in.*	*Grains.*	*Gals.*	*Grains.*
No. 6, Quicksand Creek [a]	120	860	273	30	576.1
Jackson [a]	134	675	364	36	466
Greenup County:					
No. 2 Fulton Forge [b]	170	....	209	78	543
No. 2 Fulton Forge, second trial [b]	153	....	200	99	548
No. 2 Fulton Forge, third trial [b]	145	....	189	111	555
Carter County:					
No. 1 Boghead [c]	140	670	436	40	384
No. 1 Boghead, bottom 15 inches [d]	182	675	411	40	367
Breckinridge (average of 8 trials) [e]	162	445	318	52	455
Owsley County, Haddock [f]	....	370	248.5	55	592
Youghiogheny, Pa., coal (for comparison) [f]	102	....	136	52	710

[a] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 95, 1861.
[b] Idem, p. 171.
[c] Idem, p. 111.
[d] Idem, p. 114.
[e] Idem, p. 216.
[f] Peter, Robert, Second chemical report of the ores, rocks, soils, coals, etc., of Kentucky: Kentucky Geol. Survey Second Rept., p. 217, 1857.

Gesner[1] gives a table showing the production of oil, volatile matter, and coke from a number of cannel and bituminous coals an

[1] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 56, 1865.

other bituminous substances, from which the following have been selected:

Yield of oil, coke, and volatile matter from cannel and other coals.

Locality.	Volatile matter.	Coke.	Yield of crude oil per ton.
England:	*Per cent.*	*Per cent.*	*Gallons.*
Derbyshire	48.36	53	82
Wigan cannel	44	56	74
Newcastle	35	65	48
Scotland:			
Boghead cannel	70.10	29.90	120
Scotch cannel	38	62	40
Lesmahago cannel	51	49	96
New Brunswick:			
Albertite	61.05	30.65	110
American:			
Breckinridge, Ky., cannel	61.30	38.55	130
Erie R. R., Pa	35	65	47
Falling Rock, cannel	50	50	80
Pittsburgh	36	64	49
Kanawha, semicannel	46	54	71
Elk River, semicannel	41	59	60
Cannelton, Ind., cannel	34	66	86
Coshocton, Ohio	45	64	74
Darlington, Pa. (Cannelton)	42	58	56
Camden lignite, Ark	60	40	64

He also gives the following figures showing the yield of illuminating oil and paraffin oil from Breckinridge and Boghead coal:

Refined products of oils from cannel coals.[a]

	Breckinridge.	Boghead.
Crude oil per ton of coal ....gallons..	130	120
From which are obtained:		
Illuminating oil ....do....	80	65
Paraffin oil ....do....	12	7
Paraffin ....pounds..	....	12
Making or equal to marketable oils ....gallons..	92	84

[a] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 55, 1865.

For example, Newcastle, England, cannel coal gives very different results, according to whether it is distilled for gas or for oil. The following products are reported by Gesner:[1]

Products per ton of distillation of Newcastle, England, cannel coal distilled for gas and for oil.

Distilled for gas.		Distilled for oil.	
Coal gas ....cubic feet..	7,450	Gas ....cubic feet..	1,400
Coal tar ....gallons..	18½	Crude oil ....gallons..	68
Coke ....pounds..	1,200	Coke ....pounds..	1,280
Products of the coal tar:		Products of the crude oil:	
Benzole ....pints..	3	Eupion ....gallons..	2
Coal-tar naphtha ....gallons..	3	Lamp oil ....do....	22.5
Heavy oil, naphthalin, etc ....do....	9	Heavy oil and paraffin ....do....	24
	12⅜		48.5

[1] Gesner, Abraham, Practical treatise on coal, petroleum, and other distilled oils, 2d ed., p. 110, 1865.

Gesner reports the following series of hydrocarbons as derived from Breckinridge cannel coal when distilled at an average heat of 780°: 1, C_4H_2 (supposed to exist but not condensed); 2, C_8H_4; 3, C_8H_6; 4, $C_{10}H_8$; 5, $C_{12}H_{10}$; 6, $C_{14}H_{12}$; 7, $C_{16}H_{14}$; 8, $C_{18}H_{16}$; 9, $C_{20}H_{18}$; 10, $C_{22}H_{20}$; paraffin (3–9 are stated as "embracing the hydrocarbon oils suitable for lamps when mixed"); specific gravity, 0.819.[1] "A coal from Kanawha, Va. [W. Va.], when distilled at a heat of 900° gave part of a series thus: 1, C_8H_4; 2, $C_{12}H_8$; 3, $C_{16}H_{12}$; 4, $C_{18}H_{16}$."[2]

The following table by Porter[3] shows the substances derived from tar at different temperatures:

Fractions of average coal tar and their uses.

Temperature of distillation	70°–160° C.	160°–230° C.	230°–360° C.	Above 360° C.
First crude separation by distillation.	Light oil	Middle oil (or dead oil).	Heavy oil (including anthracene oil).	Pitch.
Percentage in tar	3	8	24	65.
Intermediate products by distillation or expression.	Benzene, toluene, xylene, etc.; phenol.	Phenol, cresols, etc., naphthalene, heavy hydrocarbons.	Cresols, naphthalene, anthracene, heavy hydrocarbons, quinoline bases.	Soft pitch, hard pitch.
Crude commercial products.	Benzol and solvent naphtha for solvents, paint thinners, motor fuel, gas enrichment.	Creosote oil. Lamp black. Disinfectants	Road oils, impregnation of timber. Roofing tars. Paving tars.	Pitch, briquetting protective.
Intermediate chemical products.	Nitrobenzene, aniline salts, aniline oil, carbolic acid.	Carbolic acid, picric acid, phthalic acid, naphthols, naphthylamines, salicylic acid.	Anthraquinone alizarin.	
Refined chemical products.	Nitrotoluenes, diphenylamine, and other ingredients of explosives; aniline dyes; hydroquinone, and other photographic developers; drugs and medicines.	Picric acid, picrates, and other nitro-compounds for explosives; naphthol dyes and colors, artificial indigo, refined carbolic acid.	Alizarin dyes	

Light oil or "benzol" may also be obtained directly from coal gas, of which it forms about 1 per cent by weight. In 1913 about 4,500,000 gallons of "gas benzol" was made in addition to that used in gas enriching, and new benzol plants have since largely increased that production. Probably 3,000,000 to 5,000,000 gallons of light oil was obtained from tar in the United States in 1913. It has been estimated that if all the "benzol" were recovered from the coal used in this country for making gas and coke, it would amount to over 100,000,000 gallons.

[1] Gesner, Abraham, op. cit., p. 125.
[2] Idem. p. 126.
[3] Porter, H. C., Coal-tar products, etc.: Bur. Mines Tech. Paper 89, p. 10, 1915.

According to Lewes,[1] if coal gas is scrubbed with creosote oil, it will yield 3 to 4 gallons of crude benzene per ton of coal, containing 20 to 30 per cent of toluol.

Inubishi[2] has estimated that from the total Japanese yield of 60,000 tons of coal tar there should be obtained 230 tons of benzene, 140 tons of toluene, 200 tons of phenol, 700 tons of cresol, 3,400 tons of refined naphthalene, 8,600 tons of creosote, 7,000 tons of fuel oil, 200 tons of anthracene, and 38,000 tons of pitch.

Experiments in 1915 by the Bureau of Mines gave the following results:

	Coke (per cent).	Tar (gallons per ton).	Ammonia (pounds of sulphate per ton).	Stripped oil (gallons per ton).
"Gas enricher" cannel, Cannel City, Ky.	48	80	8	5
"Pluto" cannel, Cannel City, Ky.	65	35	5	4
Illinois bituminous	65	18	13	1.5
Pittsburgh bituminous	70	20	9	2.5

Charges, 5 to 8 pounds; maximum temperature 700° C. "Stripped oil" derived by steam distillation from "straw oil" used in washing gas, as in benzol-recovery plant. Aromatics notably absent from low-boiling tar fractions and "stripped oil."

Analysis of gas from "Pluto" cannel (3,750 cubic feet per ton) showed CO_2, 4.75 per cent; ethylene and unsaturated hydrocarbons, 8.50; H_2, 24.75; CO, 6.40; C_nH_{2n+2} (n=1.35), 54.55; N_2, 1.05.

The experiments showed, according to Dr. G. B. Taylor, of the Bureau of Mines, not only that cannel coal differs from other bituminous coals in the larger volumes of tar or oil and gas it yields, but that because of the low temperature at which the liquid products come off they consist mainly of saturated and unsaturated paraffin hydrocarbons, together with tar acids and but little of the valuable benzene and toluene. The low-temperature oils are difficult to refine and as yet have found no ready market. Their possible uses are as flotation oil and as sources of gasoline and creosote. The difficulty in refining for gasoline comes in removing the unsaturated bodies, notably paraffins of the ethylene series. Hydrogenation may in the future obviate this difficulty. Many studies are yet needed of tar and gas derived from cannel coal at high temperature and of the results of "cracking" or other subsequent treatment of the low-temperature distillation products.[3]

[1] Lewes, V. B., The place of the gas industry in the manufacture of modern explosives: Gas World, vol. 62, p. 242, 1915.

[2] Inubishi, S., Japanese by-product industry: Gas Age, vol. 35, p. 268, 1915.

[3] Rittman, W. F., The Rittman gasoline process: Nat. Petroleum News, vol. 7, pp. 2-4, 1915. Since the above was written the Bureau of Mines has issued a bulletin by Rittman, Dutton, and Dean (Bull. 114), describing in detail the Rittman and other processes for the cracking of oils and the methods of producing the aromatic hydrocarbons used in making explosives, including a very complete bibliography on these and related subjects.

CANNEL-COAL MINING.

PENNSYLVANIA.

The early use of cannel coal is largely merged in that of bituminous coal. According to Mansfield[1] the cannel coal of Cannelton, Pa., appears to have been known to the Indians at least as early as 1750, and was used by them in their hunting camp at the mouth of Cannel Ravine. William and George Foulks, who were for a time held prisoners by the Indians, seem to have been the first white men to learn its source. It was certainly known to white men in 1787. The first mine was opened by William Welch but was burned out in a raid on horse thieves, who had made the locality a hiding place. It is of record that the cannel mine was purchased in 1820 by James Patterson and operated for two years. When the Pennsylvania & Ohio Canal was projected in 1831, a survey was made for a "cannel-coal railway" from New Galilee to Newcastle. Though often the subject of ownership disputes, the cannel coal at this point appears to have been worked more or less regularly on a small scale. A railroad was built to the mines in 1855, and from that time mining continued extensively until 1900. (See Pl. IV, *A*, p. 34.)

OHIO.

In Ohio cannel coal was mined in the Flint Ridge region at least as early as 1830 and 1840. Data as to the discovery of the other cannel fields in the State were not obtained, but it is believed that most of them have been known and some of them mined from a very early date. The fact that oil refineries existed at Coshocton, Canfield, and Zanesville, Ohio, before 1860 is itself evidence that the neighboring cannel coals were then being mined.

INDIANA.

In 1837 the American Cannel Coal Co., of Cannelton, Perry County, Ind., was incorporated and began to mine at that point. Cannel coal mining at Cannelsburg, Daviess County, Ind., was begun in 1871 by the Buckeye Cannel Coal Co., and has been continued to the present time.

WEST VIRGINIA.

In West Virginia, according to Edwards,[2] cannel coal began to be exploited on Coal River in the early forties through the activity of

[1] Mansfield, I. F., Fireclays, coals, and titles of the cannel-coal tract at Cannelton, Beaver County, Pa., p. 27, 1905.

[2] Edwards, W. S., Coals and cokes of West Virginia, pp. 96–98, 1892.

W. N. Peyton. Among the companies engaged were the Virginia Cannel Coal Co., with mines at Peytona, in Boone County; the Western Mining & Manufacturing Co., with mines at Drawdy Creek near Peytona; the Cannel Coal Co. of Coal River, with mines at Manningville on Little Coal River; and the Coal River & Kanawha Mining & Manufacturing Co., with mines at Briar Creek, in Boone County. These companies organized the Coal River Navigation Co., which built eight locks and dams on Coal River and one on Little Coal River, with an average lift of 10 feet, giving 4 feet of water at all seasons. The cannel-coal trade on this river reached a maximum output of about 200,000 tons a year, the coal going mainly to markets on the lower Ohio. During the Civil War the mines were abandoned, the markets closed, and the neglected locks and dams washed out. After the war the Virginia Cannel Coal Co. was reorganized as the Peytona Cannel Coal Co. The river was redammed, but after 10 years of financially unsuccessful mining the project was abandoned until a railroad should be built up the river.

About the time development began on Coal River cannel coal was discovered on Kanawha River below Smithers Creek by Aaron Stockton, and in the early fifties a refinery was established at Cannelton to extract oil and paraffin from the Stockton bed. Cannel coal began to be mined on Paint Creek in 1857 and was used in an oil refinery established there. Edwards[1] says that an unsuccessful attempt was made at Forest Hill to manufacture oil from bituminous shale. Cannel coal was discovered on Twelvepole Creek at a much later date, and development did not begin until the construction of the Norfolk & Western Railroad through that district. These last deposits of cannel coal proved to be very small.

According to Newberry[2] cannel coal was also known on Mill Creek and on Falling Rock Creek before the war and for a time an oil refinery was operated 1½ miles above the mouth of Falling Rock Creek.

KENTUCKY.

Just when cannel-coal mining began in Kentucky was not learned. Mather,[3] writing in 1838, said that a bed of cannel at the mouth of Troublesome Creek, on Kentucky River, was being regularly mined and shipped down the river in flat boats, but he made no mention of mining on Georges Branch or on Quicksand Creek, though it is possible that the coals at those points were being worked at that time or were opened up soon thereafter. In 1837 the Breckinridge cannel, which had been known for several years, was being mined and hauled

[1] Edwards, W. S., op. cit., pp. 85–86.
[2] Newberry, J. S., Ohio Geol. Survey Rept., vol. 2, pt. 1, Geology, p. 547, 1874.
[3] Mather, W. W., Report on the geological reconnaissance of Kentucky made in 1838, p. 15, 1839.

to Ohio River, where it sold for the use of steamers at 10 cents a bushel. Trimble,[1] writing in 1837, says that it sold in Louisville at that time at 15 cents a bushel. He adds: "The cannel coal of Kentucky River is believed to be superior to any of that species in America, and is evidently superior to the coal imported under that name. * * * Many veins of it have been found on the Kentucky River." Some idea of the extent of the mining of the Breckinridge cannel may be gained from the fact that, writing in 1855, Owen[2] mentions measuring sections in rooms off the eighth entry.

The coals mentioned were probably the only cannels that were being mined in Kentucky in 1855. Other cannels were known, however, and were probably mined in Greenup, Carter, Johnson, and possibly some other counties before 1860.

PRODUCTION.

The figures in the following table, showing the production of cannel coal in the United States,[3] are fairly complete for years since 1902 but not for preceding years. The term "semicannel" in the table is the term used by the mining companies in their reports and does not mean the coal so named in this paper (p. 10).

Production of cannel coal in the United States, in long tons.

State.	1892 Cannel.	1892 Semi-cannel.	1902 Cannel.	1902 Semi-cannel.	1903 Cannel.	1903 Semi-cannel.	1904 Cannel.	1904 Semi-cannel.
Indiana			30,000		35,900		32,350	
Iowa	1,401		15,000		19,621		13,127	
Kentucky	25,383	21,887	63,717	1,600	118,616	19,390	80,592	51,811
Missouri	2,486		446		700		7,521	
Montana					650		700	
Ohio	27,798		3,007				8,588	
Pennsylvania	25,920		30,905		1,154		5,807	
West Virginia			10,000	124,701	14,014	122,049	22,800	166,904

State.	1905 Cannel.	1905 Semi-cannel.	1906 Cannel.	1906 Semi-cannel.	1907 Cannel.	1907 Semi-cannel.	1908 Cannel.	1908 Semi-cannel.
Alabama					14,722			
Indiana	32,475		25,475		38,455	2,200	30,230	
Iowa	15,612		13,020		10,800		22,718	
Kentucky	138,408	15,397	73,083	4,650	97,586		82,933	6,201
Missouri	2,500		5,100		1,859		4,183	
Montana	150							
Ohio	2,362		3,836		400		865	
Pennsylvania	3,819		6,160		14,772		24,307	
Texas	78,500				2,200			
West Virginia	18,167	238,844	14,480		13,681		64,369	

[1] Trimble, D., Report of the committee on the coal trade and iron interests of Kentucky, p. 8 [1837?].

[2] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 175, 1856.

[3] U. S. Geol. Survey Mineral Resources.

Production of cannel coal in the United States, in long tons—Continued.

State.	1909		1911		1912		1913	
	Cannel.	Semi-cannel.	Cannel.	Semi-cannel.	Cannel.	Semi-cannel.	Cannel.	Semi-cannel.
Indiana	22,676	....	11,875	....	7,373	....	....	....
Iowa	21,672	....	....	....	8,344	....	5,628	....
Kentucky	67,869	....	90,275	....	88,292	86,377	90,124	86,263
Missouri	5,936	....	....	....	3,583	....	3,931	....
Ohio	33,778	....	5,683	....	4,039	....	5,994	....
Pennsylvania	51,347	....	39,879	....	68,091	....	58,174	....
Tennessee	....	....	8,048	....	12,500	....	6,703	....
West Virginia	119,844	121,000	14,250	....	28,848	206,585	10,303	....

The following mines have recently been operating on cannel coal. Those marked with a * were not reported as operated in 1916.

Indiana:

Mutual Coal Co., Cannelsburg; Mutual mine.*

Iowa:

Webster County—Craig & Dawson Coal Co., Fort Dodge; Cannel No. 2 mine.

Kentucky:

Bell County—Federal Coal Co., Chattanooga, Tenn.; Wallsend, Chenoa.

Carter County—Eastern Kentucky Railway Co., Riverton; Boghead mines.*

Floyd County—Puritan Cannel Coal Co., Prestonburg.

Greenup County—Eastern Kentucky Railway Co., Riverton; Hunnewell mine.*

Harlan County—Cumberland Cannel Coal Co., Welch, W. Va.; No. 1 mine.

Johnson County—

East Kentucky Coal Co., East Point.*

Ayers & Lang, Detroit, Mich.

Greasy Creek Coal Co., Thealka.

Whitehouse Cannel Coal Co., Myrtle.*

Knox County—North Jellico Coal Co., Lewisville; Olive Hill mine.

Morgan County—

American Consolidated Cannel Coal Co., Loveland; No. 1 mine.*

Bigstaff Cannel Coal Co., Cannel City; Bigstaff mine.*

Caney Cannel Coal Co., Paris; Caney mine.*

Gish Cannel Coal Co., Central City; White Oak mine.

Kentucky Block Cannel Coal Co., Cannel City; No. 1 and Brushy mine.

Lee Cannel Coal Co., Clearfield; Lee No. 1 mine.

Mayflower Cannel Coal Co., Lancaster; Eureka mine.*

Charter Coal Co., Frankfort; Nos. 1 and 2 mines.

Orley Hanley, White Oak; Little mine.

Whitley County—Halsey Red Ash Coal Co., Halsey; Anderson and Vanderpool mines.

Missouri:

Callaway County—W. C. Weeks.

Cole County—S. & A. Bandelier, Elston.*

Moniteau County—

Monarch Coal & Mining Co., Excelsior.*

Rohrbach-Rowlin Mining Co.*

Newkirk Mining Co.*

Morgan County—Hubbard & Moore.*

Ohio:
  Coshocton County—
    Dailey Cannel Coal Co., Mohawk Village; Dailey mine.*
    Ohio Block Cannel Coal Co., Toledo; Flambo mine.
    Ohio Cannel Coal Co., Coshocton; Ohio mine.
  Mahoning County—American Fire Clay Co., Cleveland.
Pennsylvania:
  Butler County—Butts Cannel Coal Co., Deegan.
  Center County—Lula Coal Mining Co., Philipsburg; Lula mine.
  Clearfield County—
    A. Stolz, Houtzdale; Katherine mine.
    Hurley, Wilson & Law, Houtzdale; Keystone mine.*
    A. B. Lansberry, Woodland; Mines Nos. 2 and 3.
    Woodland Cannel Coal Co., Woodland; Cannel Crest.
    Washington Jury, Woodland.
  Indiana County—Altoona Coal Co.
  Armstrong County—
    Fairmont Coal Co., Buffalo, N. Y.; Mines Nos. 8 and 9, Bostonia.
    Pine Run Coal Co., New Bethlehem; Brooks No. 1 and Cooke.
  Westmoreland County—W. E. Brown & Co., Ligonier; Darlington mine.
Tennessee:
  Campbell County—Jellico Cannel Coal Co., Massillon, Ohio; Hermitage mine.*
Texas:
  Webb County—
    Santo Tomas Coal Co., Santo Tomas.
    Cannel Coal Co., Dolores.
West Virginia:
  Boone County—Peytona Block Coal Co., Peytona; Cannel mine.
  Kanawha County—
    Paint Creek Collieries Co., Scranton, Pa.; Wacomah mine.*
    Mill Creek Cannel Mining Co., Cleveland, Ohio; Mill Creek.
    Weirwick Cannel Coal Co., Weir.*
  Wayne County—Wells Branch Coal Co., Wells Branch.

VALUE.

The natural question arising in the mind of anyone thinking of buying cannel coal is why it is so expensive. Doubtless the principal reason is the well-known law of supply and demand. The total supply of cannel coal is very small, and the coal is distributed in small basins or pockets, hardly any of which would pay for the installation of a modern mining plant of any size, even at present prices of cannel coal. Most of the deposits are not closely adjacent to railroad transportation and are not extensive enough in themselves to warrant building a spur of any length. Further, the demand for use in grates, the principal demand in recent years, has been for coal in blocks, so that the fine coal necessarily made in mining has not found a market. If the distillation of cannel coal for oil and other by-products is resumed all the coal will find a market, but the increased demand is as likely to raise the general price as to lower

In many of the basins, by careful hand mining, the whole

product may be gotten out in block form. In others the wastage, because of the restricted demand of the market, may be as high as one-half. The whole product (including the slack) of coals rich in gas, or those having 50 to 60 per cent of volatile matter and a correspondingly high candlepower, will always find a readier market, while the drier cannels and semicannels will find a more restricted market for the blocks only and will therefore have a correspondingly larger percentage of waste.

The labor cost of cannel coal, f. o. b. cars at the mine, should not, as a rule, be more than $1 per ton of total product.[1] If only one-half of the product can be marketed the marketed coal must bear the cost, or, say, $2 per ton. Where the mines have no railroad connection the cost of hauling to the railroad must be added to the other costs of mining. In some fields containing the richer cannels the miners are paid high prices for mining. At one place visited by the writer the miners were receiving $2.50 a ton, besides being given a bench of bituminous coal associated with the cannel. The mine, however, was a small one, and the miner not only mined his coal but pushed it out to the tipple and attended to all the handling it received until it was placed on the cars. As the cannel being mined was very rich and brought a high price, well above the average of other cannels, the owner could doubtless well afford the price he paid. In other places the methods of mining and of transportation are very expensive, involving, for instance, the frequent handling of the coal by hand, as large bricks might be handled. (See Pl. I, p. 12.)

The selling price of cannel at the mines is usually about double that of bituminous coal in the same district. Thus, in 1904 true cannel coal in Kentucky was bringing from $1.97 to $2.49 at the mines as against 80 cents to $1.50 for bituminous coals. Cannel coal in the Clearfield district of Pennsylvania was bringing $1.80 to $2 as compared to 89 cents to $1 for bituminous coals of the same district. Ohio cannels brought $3.25 as compared with $1.20 to $1.80 for bituminous coals in the same district. West Virginia cannel brought $2.23 as against 80 cents to $1.32 for bituminous coals.

Most of the mine inspector's reports for Kentucky give the selling price of cannel coal at the mine. The following table gives the selling prices of cannel and bituminous coals for selected years:

Selling prices per ton of cannel and bituminous coals in Kentucky.

Year.	1903	1904	1905	1906	1907	1911
Cannel	$2.40	$2.03	$2.44	$2.40	$2.60-3.26	$2.51
Bituminous	1.05	.98	.97	1.00	1.05	.98

[1] Under pre-war conditions.

According to the Coal Trade Journal for 1910, American cannel coals sold in New York that year at $13 to $14 a ton and imported cannels at $16 to $17 a ton. Prices in Chicago and other places having a shorter freight haul were correspondingly lower.

DISTRIBUTION.

PENNSYLVANIA.

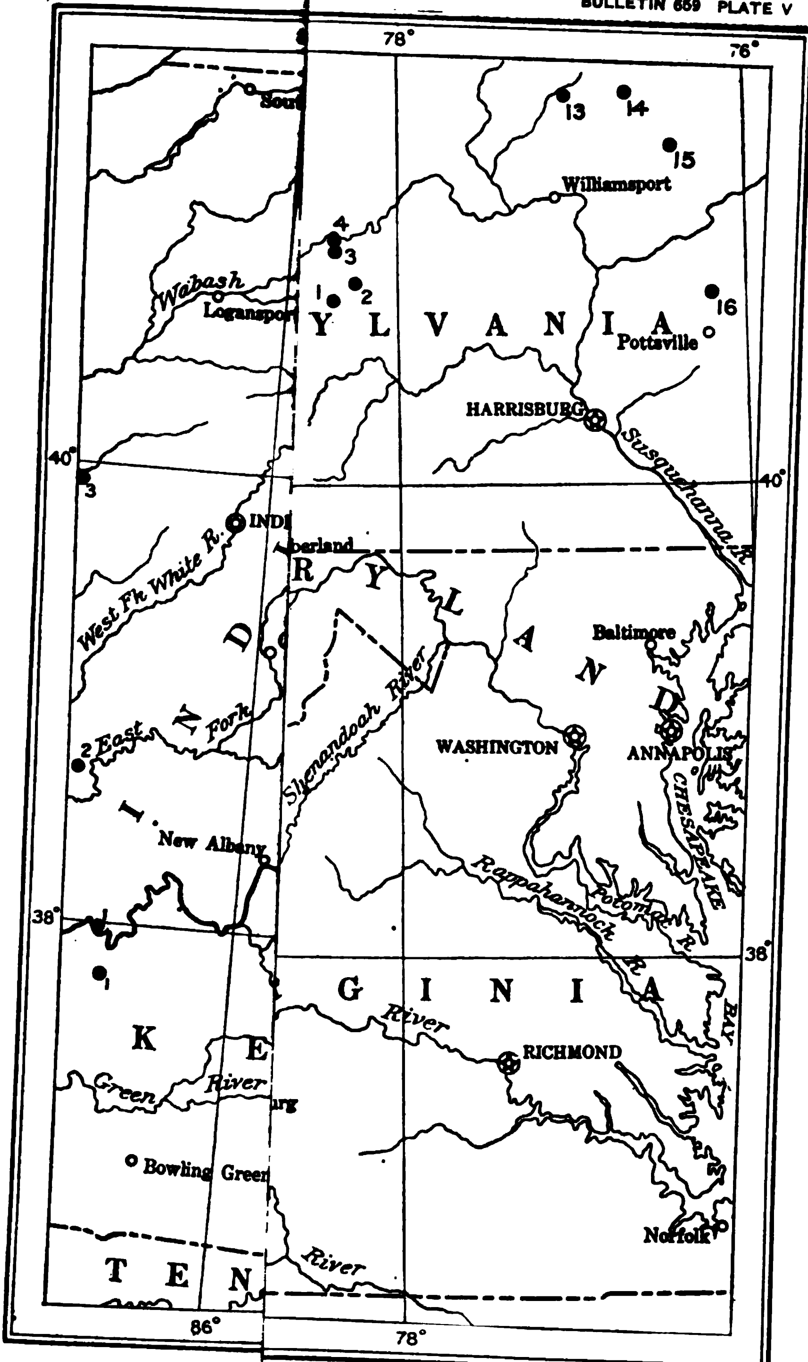
REVIVAL OF THE INDUSTRY.

Cannel coal has long been mined (see p. 50) in Pennsylvania at Cannelton, in Beaver County, and at different times in Armstrong, Indiana, and Clearfield counties. (See Pl. V.) In 1914 the writer made a special trip through the Pennsylvania coal field, visiting or revisiting nearly or quite all of the cannel-coal mines then operating in the State. At that time he was surprised to find that several of the old mines had been reopened and were being operated extensively and that one country mine, formerly visited, was being opened up on a commercial scale, involving the building of a narrow-gage tram road several miles long. The special purpose of the writer's trip was to obtain specimens for testing for the production of oil. (See pp. 45–46.) In the following pages most of the deposits described are, or have been, or give promise of becoming commercial propositions. All the cannel coal in Pennsylvania, except that in Beaver County and one or two other places, appears to be semicannel.

CENTER COUNTY.

Philipsburg.—A bench of semicannel or canneloid coal occurs in the B bed, where mined by the Lula Coal Mining Co. about a mile southwest of Philipsburg (location 2 [1]). When visited, it was estimated that at least 100 acres, and possibly several times that area, under the wide creek bottoms was underlain by about 4 feet of cannel lying between two benches of bituminous coal. The cannel is 4 feet thick in part of the mine, but to the southeast it pinches down to 5 inches or less. To the north and west it runs out under the broad creek bottoms and is reported to have been struck in a well on the west side of the valley. Where it is thick the upper bench of bituminous coal (27 inches thick) is undercut and the cannel is raised. Where it is thin the whole bed is undercut by electrical machines. (See fig. 2, section 1.) The cannel gives an abundant white ash, ranging probably from 15 to 20 per cent. (See also pp. 12, 13.)

[1] Location numbers for Pennsylvania appear on Plate V.



MAP OF PART OF AS SHOWN ON LARGE-SCALE MAPS IN

rs for each State.

CLEARFIELD COUNTY.

Moshannon Creek.—A small basin of cannel coal occurs on Moshannon Creek (location 1) just above the mouth of Whiteside Run, a few miles southeast of Houtzdale. It has been mined at the Kath-

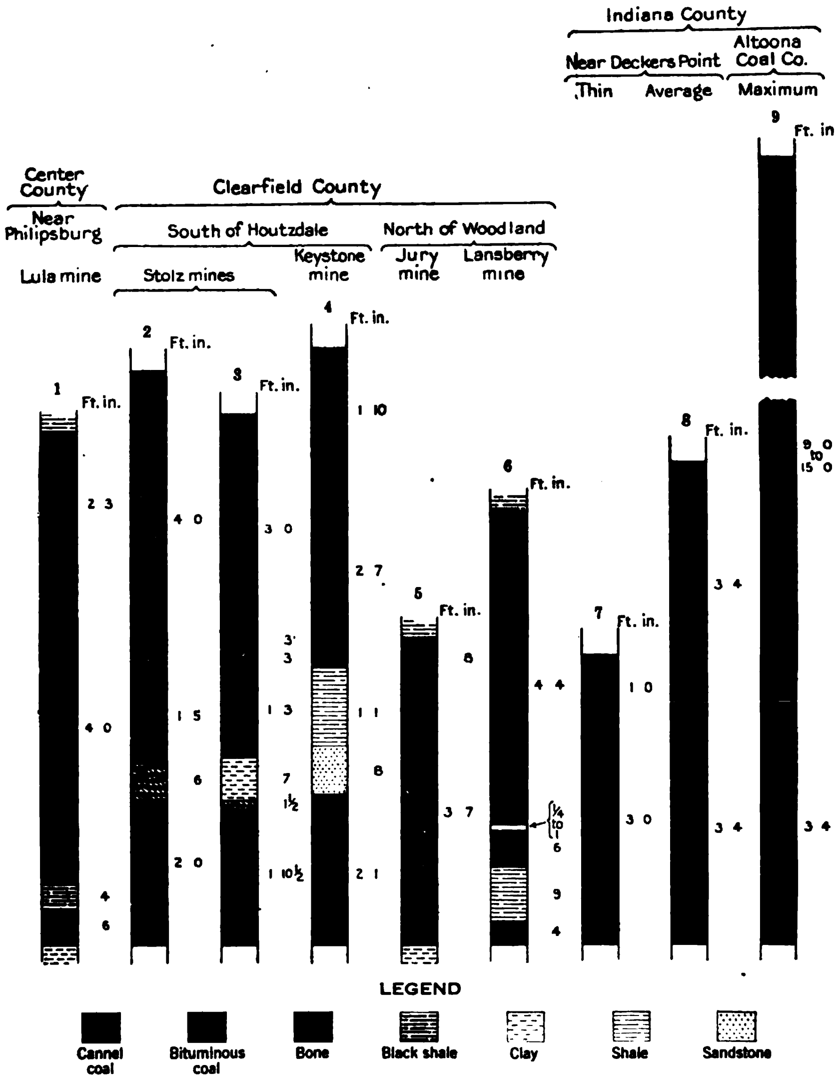


FIGURE 2.—Sections of cannel coal in Center, Clearfield, and Indiana counties, Pa.

erine mine of A. Stolz and at the Keystone mine of Hurly, Wilson & Law. The cannel portion of the bed has a maximum thickness of 4 feet and is associated with 2½ feet or less of bituminous coal. The extent of the bed is not known, but the variability of cannel beds at

points not far distant indicates that it is probably not over a few hundred acres. (See fig. 2, sections 2–4.)

Woodland.—Cannel coal was formerly mined in the hills immediately north of Woodland and is still being mined 1½ miles north of that town (locations 3 and 4). In the hills two beds formerly mined were known as the red-ash cannel and the white-ash cannel (correlated as the C′ or Upper Kittanning and the C or Middle Kittanning coals). The coal reached a maximum of 4 feet just north of the east end of town. Whether this basin extends northward to the area in which mining is now being done is not known. Probably it does not, though considerable cannel may lie between the two points.

One and one-half miles north of Woodland cannel coal is being mined by A. B. Lansberry and, for wagon trade, by Washington Jury. The Lansberry mine is connected by tram with the New York Central Railroad near the tunnel 5 miles below Clearfield, on Susquehanna River. Several openings have been made on the coal, which shows about 4 feet of cannel, associated with a small amount of bituminous coal. (See fig. 2, sections 5, 6.) In this cannel, as in that at Lula, the fracture is not typical but resembles that of the bituminous coals of the region.

INDIANA COUNTY.

Richmond.—Rather thick beds of cannel coal have been opened at several places south of Richmond (location 5), a station south of Punxsutawney on the Indiana branch of the Buffalo, Rochester & Pittsburgh Railway.

At one opening the Altoona Coal Co. was, in 1914, making preparations to ship cannel coal commercially. The bed, which is correlated as the C′ or Upper Kittanning, consists of 3 feet or less of bituminous coal overlain by from 1 to 15 feet of cannel. The cannel part of the bed is thought to occupy a narrow north-south basin extending southward from this point toward Deckers Point, where it has been mined on a small scale on the George Barr place. It has the appearance of a true cannel, but chemically it is a low-volatile cannel or semicannel, showing only 23 to 24 per cent of volatile matter in contrast with 30 per cent in the underlying bituminous coal. At the Barr opening the cannel portion of the bed is only 15 inches thick, and at the old Lowry mine, later opened up by the Altoona Coal Co., it was seen to change from 9 feet to 1 foot in a very short distance.[1] (See fig. 2, sections 7–9; and analyses 166, 167, p. 27.)

[1] Platt, W. G., Report of progress in Indiana County: Pennsylvania Second Geol. Survey Rept. H4, pp. 228–231, 1878.

WESTMORELAND COUNTY.

The Pittsburgh coal bed carries a little cannel coal in many places in Westmoreland County, and at many more is overlain by cannel shale. Stevenson[1] says that in Burrwell Township, 2 miles west of McLaughlin (locality 12), the top bench of the Pittsburgh coal carries 4 to 10 inches of cannel.

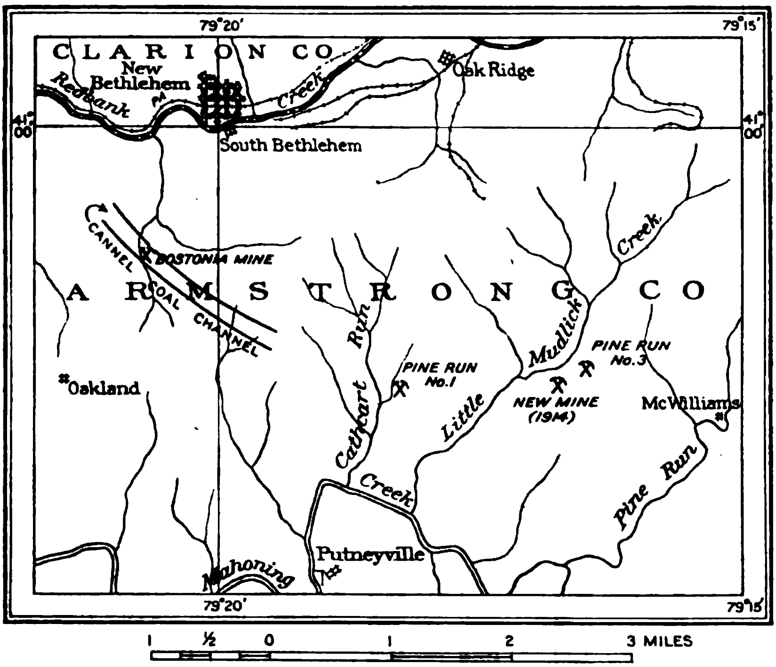


FIGURE 3.—Sketch map of area of cannel coal south of New Bethlehem, Armstrong County, Pa.

ARMSTRONG COUNTY.

South of New Bethlehem.—In 1914 most of the cannel coal mined in Pennsylvania came from a small district south of New Bethlehem (locations 6–9) on the low-grade division of the Pennsylvania Railroad. Cannel coal was mined by the Fairmont Coal Co. at Bostonia (location 9), 1½ miles south of New Bethlehem, and by the Pine Run Coal Co. on Cathcart Run, and on Little Mudlick Creek. (See fig. 3.)

The coal being mined is the C′ or Upper Kittanning. The cannel coal appears to lie in a narrow basin, whose axis extends northwestward across the head of a small ravine emptying into Redbank Creek just below New Bethlehem. In the Bostonia mine the maximum

[1] Stevenson, J. J., Pennsylvania Second Geol. Survey Rept. K2, p. 369, 1877.

minable width of the basin is about 800 feet. In the center there is 9 feet of cannel over 18 inches of bituminous coal. The channel, here nearly straight, had in 1914 been mined out for 2,000 feet to the northwest and 5,300 feet to the southeast of the ravine crossing nearly halfway through the divide between the mine and Cathcart Run. (See fig. 4, section 11.)

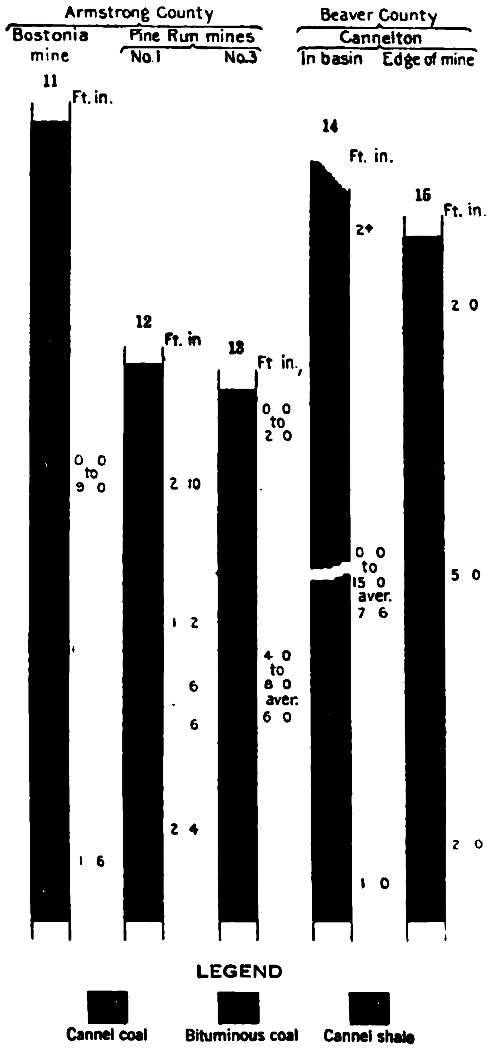


FIGURE 4.—Sections of cannel coal in Armstrong and Beaver counties, Pa.

The cannel reaches Cathcart Run about a mile from the mouth and is being mined on the east side at mine No. 1 of the Pine Run Coal Co. (location 8). From there the channel runs eastward, reaching Little Mudlick Creek, nearly 2 miles from the mouth. In 1914 cannel coal was being mined at No. 3 mine of the Pine Run Coal Co. (location 7), and a new mine was being opened a short distance to the south. The same bed has been opened up again east of Charleston on the Jacob Schiech farm (location 6).

At the Pine Run No. 1 mine, on Cathcart Run, the cannel coal (analysis 162, p. 26) is in two benches, the upper from less than 3 feet to more than 5 feet thick and the lower from 6 inches to 7 feet thick, separated by 12 to 20 inches of "mixed" coal, all underlain by 2 feet or more of bituminous coal. The mixed coal bench has 6 inches of bituminous coal at the bottom and the rest is "curly" cannel, with possibly streaks of bituminous. Both the cannel and bituminous coal here are irregular, for as the cannel thins the bituminous coal thickens, reaching 5 feet at the back of the mine.

At the Pine Run No. 3 mine the cannel is 4 to 8 feet thick (averaging about 6 feet) and is overlain in most places by bituminous coal of a maximum thickness of 2 feet. In places a little bituminous coal is found under the cannel. The cannel runs out in entries to the north but holds its thickness in those to the east. The new opening, a short distance to the south, appears to be in a branch of the channel from the south, for the cannel thins to the east but holds up to 7 feet southward. At all of these mines a considerable portion of the mined coal, though possibly suitable for making oil, does not meet the trade demand which calls for a smooth even block. Even the amount of oil in these cannels is small, as shown by the tests and analyses. (See fig. 4, sections 11–13, and analyses 160–163, p. 26.)

The channel is nearly straight at the Bostonia mine, but to the southeast it appears to become crooked and irregular and probably divides into branches. Whether the several channels so far located connect and form parts of the same channel or system of channels is not certain. Search has not yet revealed cannel coal on the west side of Pine Run or Little Mudlick Creek. The cannel-coal channels found appear to belong to the same system.

The cannel coal lies in a channel distinctly depressed in the middle. (See p. 32.) The coal bed is much broken up by slips or cracks filled with clay, sandstone, or sulphur. Some of these are nearly vertical and some are irregular, ranging in width from next to nothing to 16 feet. These clay slips interfere greatly with mining the coal into dimension blocks (as they would be called in the stone industry); and as the trade demands mainly coal in that form it has been necessary to "gob" or store outside about half of the product of the mine. In some places these clay "veins" have been pierced by drillings, making it appear that the coal bed was absent at that point.

Somerville.—Near Somerville, in the northwest corner of Armstrong County (location 10), the Upper Kittanning is locally 2 to 12 feet thick, comprising 2 to 5 feet of bituminous coal underlain by a maximum of 7 feet of low-grade cannel. It has been mined at the Ganner mine. The coal here occurs, as in many other places, in narrow, irregular depressions or concavities. Beyond the limits of the depression the bed is locally scarcely more than a streak in the rocks. Its occurrence at the Ganner mine is described by Platt[1] as follows:

A good exhibition of its cannel-slate feature may be had at the Ganner mine in the ravine of Holder Run, at which place the bed is 2 feet thick at the outcrop, increasing within a short distance to 5 feet of bituminous coal of a fairly good quality. The floor of the seam then rapidly descends at an angle of 10°

[1] Platt, W. G., Report of progress in Armstrong County: Pennsylvania Second Geol. Survey Rept. H5, p. 222, 1880.

to a depth of 7 feet, the roof mainly remaining horizontal. The interval between is gradually occupied by a mass of impure cannel slate of a dull luster and having conchoidal fracture.

ALLEGHENY COUNTY.

In Allegheny County the Pittsburgh bed carries at its top 2 feet of impure cannel at the Brewer bank and the Upper Freeport coal a similar thickness around Hiteston, both in West Deer Township.[1] The Elk Lick coal carries 6 to 12 inches of cannel at several places, as in Reserve and McClure townships and on Duff Run, in Franklin Township.[2] Near Allegheny City the Elk Lick coal is represented by 1 to 2 feet of cannel or cannel shale, and at Bakerstown the Bakerstown coal carries 6 to 12 inches of cannel at its base.[3]

BUTLER COUNTY.

A little cannel coal has been found at several places in Butler County. On Breakneck Creek, in Adams Township, 4 to 6 inches of cannel lies at the top of the Upper Freeport.[4] A thin bed of cannel lies at the top of the Bakersfield coal near the head of the south branch of Glade Creek, in Middlesex Township, and another lies at the horizon of the Mahoning coal in Forward Township.[5] In Jackson Township along Breakneck Creek[6] the Lower Freeport carries a foot or more of cannel. In Lancaster Township on Yellow Creek[7] a coal thought to be below the Lower Freeport carries 1 foot of cannel and 3 feet 4 inches of bituminous coal that has a semicannel structure.

BEAVER COUNTY.

The famous Cannelton bed in the northwest corner of Beaver County, north of Cannelton (location 11), appears to occupy an old channel. It consists of three parts, a bench of bituminous coal 6 to 12 inches thick at the bottom overlain by 6 to 12 or more feet of cannel coal, which grades upward into a rich cannel shale, in places 6 feet in thickness. The bituminous coal at the bottom is interlaminated with streaks of cannel. The channel has a width of about 600 feet. For a width of 300 feet in the center the coal maintains a

[1] White, I. C., Report of progress in the Beaver River district: Pennsylvania Second Geol. Survey Rept. Q, pp. 148, 150, 1878.
[2] Idem, p. 173.
[3] Idem, pp. 28, 32.
[4] Idem, p. 75.
[5] Idem, pp. 78, 106.
[6] Idem, pp. 114–115.
[7] Idem, p. 121.

good thickness, averaging 7 or 8 feet and ranging up to double that. At the edges of the 300-foot channel the coal averaged 6 feet, but outside of that the sides of the channel rose abruptly to a height in places 20 feet above the bottom of the basin and the coal thinned against the sides and almost or quite pinched out at the top. Mining has shown that the cannel follows an oval course, with a maximum diameter of 2 miles and a minimum diameter of 1 mile. (See fig. 4, sections 14, 15, and analyses 164, 165, p. 27.)

In South Beaver Township the Darlington coal is overlain by 10 to 15 inches of cannel, grading into 4 to 5 feet of cannel shale.[1] In Industry Township the Kittanning coal carries in places as much as 14 inches of cannel at its base.[2] In Economy Township the shale just above the Upper Freeport coal locally takes on the appearance of cannel. Opposite Beaver Falls (location 18) a local bed of cannel in the Freeport sandstone reaches a thickness of 5 feet but has a length of only a few rods.[3] In North Sewickley Township the Brush Creek coal becomes at one point a bed of cannel reported as 5 feet thick and fairly good, and at another point, on a tributary of Brush Creek (location 17), carries 4 feet of good cannel overlain by 1 foot of shaly cannel and underlain by 1 foot of bituminous coal.[4] In Marion Township the Darlington coal is overlain by 2 feet of cannel or cannel shale on Brush Creek.[5] In Pulaski Township on Trough Run the Lower Freeport is locally impure cannel coal 3 feet thick.[6] North of that in New Sewickley Township the Darlington coal carries 6 inches of cannel on Cow Run.[7]

OHIO.

Much cannel coal occurs in Coshocton, Jackson, Licking, and Mahoning counties, Ohio (Pl. V, p. 56), but none of it runs as high as 50 per cent in volatile hydrocarbons. (See analyses 141, 142, 149–157, p. 26.)

MAHONING COUNTY.

The most important bed in Mahoning County is the No. 4 or "cannel seam," which, according to Newberry,[8] contains 6 feet of cannel of good quality. In the southwest corner of Canfield Township, on the Wetmore place, it is 5 feet thick (location 1[9]), nearly all

[1] White, I. C., Pennsylvania Second Geol. Survey Rept. Q, p. 238, 1878.
[2] Idem, p. 260.
[3] Idem, pp. 50, 202.
[4] Idem, pp. 36, 213.
[5] Idem, p. 215.
[6] Idem, p. 200.
[7] Idem, p. 186.
[8] Newberry, J. S., Ohio Geol. Survey Rept., vol. 3, pt. 1, pp. 795, 796, 806–810, 1878.
[9] For Ohio the locations are numbered by counties. (See Pl. V, p. 56.)

cannel. On the Irving farm near by it comprises only 6 inches of cannel over 2 feet of bituminous coal. In Springfield and Beaver townships it has been opened at many points and shows "in some places, 6 feet thick of cannel, in others 3 feet thick, half cannel and half cubical coal, and in still others 3 feet thick with 6 inches of cannel on top. Where of cannel it contains on the average about 15 per cent of ash."

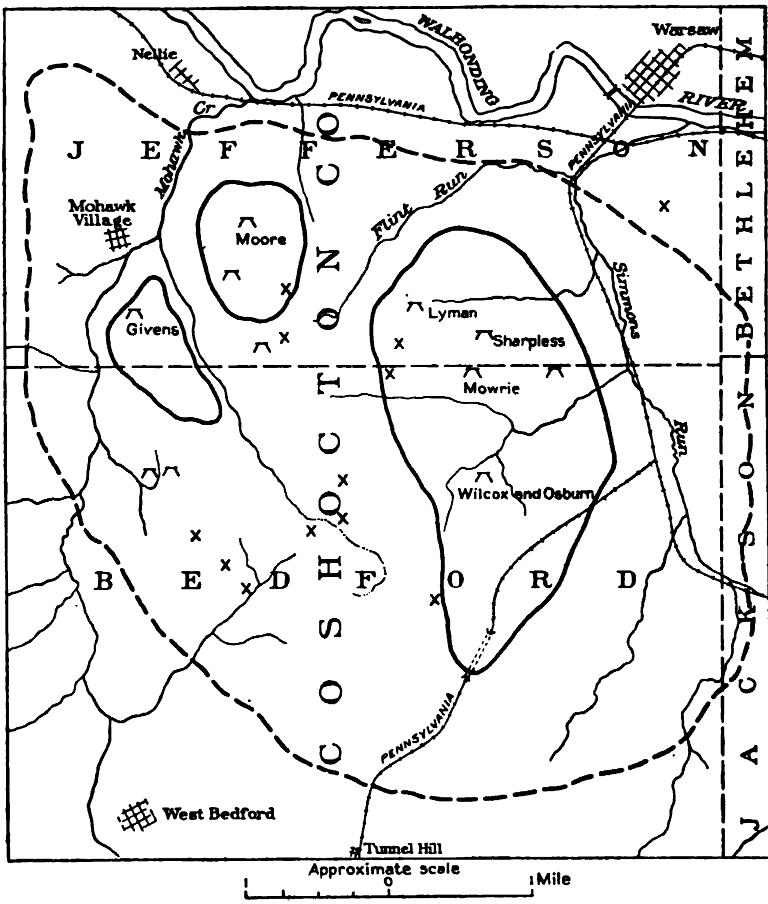


FIGURE 5.—Sketch map of cannel-coal basin in Jefferson and Bedford townships, Coshocton County, Ohio. (After Orton.)

The sections suggest that the cannel of workable thickness is in very small pockets. The Canfield cannel lies immediately below the "ferriferous or Vanport limestone."

COSHOCTON COUNTY.

In Bedford and Jefferson townships (location 4), Coshocton County, the coal known as Bedford cannel lies at the Upper Mercer

horizon; total area is 12,000 to 13,000 acres, of which it is estimated that nearly 1,500 acres in three distinct basins will yield coal over 2 feet thick. In its best exposures the coal is 6 feet thick; and in several openings it comprises 5 feet or more of cannel overlain by

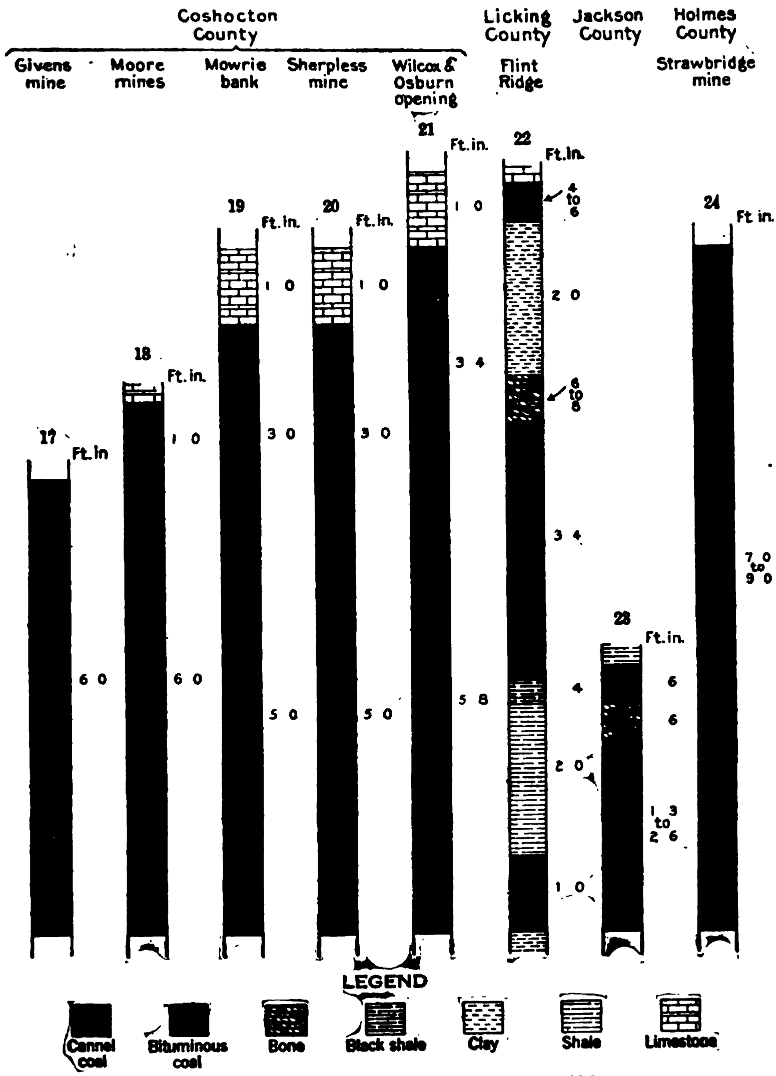


FIGURE 6.—Sections of cannel coal in Ohio.

3 feet of bituminous coal. Nearer the boundaries the cannel thins and changes into an impure bone coal or a rich, block shale. The area of the field and the location of the sections is shown on figure 5.[1]

[1] Orton, Edward, Ohio Geol. Survey Rept., vol. 5, Economic geology, p. 846 (map), 1884.

The following notes are condensed from a description of the field by Orton[1] published in 1884. Coal over 2 feet thick is confined to three areas. In one, which lies south of Mohawk, the cannel as exposed at the Givens mine is 6 feet thick but has less luster and a less conchoidal fracture than that in the other areas. (See fig. 6, section 17.)

Another tract a mile east of Mohawk has been opened on the Moore Bros. places, where the cannel is 6 feet thick overlain by 1 foot of bituminous coal. The coal mines without powder, in blocks large and durable enough to be used locally for horse blocks, stepping stones, and the like. East of the Moore mines the coal thins down, but east of Flint Run bottoms it thickens again. At the Mowrie and Lyman banks it is 5 feet thick. At the Mowrie bank it is unusually hard and firm and is exclusively close grained and curly; the joint structure is so little developed as to make the use of powder necessary in mining. At the Sharpless mine the coal is highly conchoidal. The analysis given on page 26 represents the run of mine at this opening, including the whole bed. The coal is said to reach a thickness of 9 feet in the Wilcox & Osburn opening. (See fig. 6, sections 17–21, and analyses 141, 142, p. 26.)

LICKING COUNTY.

The Flint Ridge cannel comes from Hopewell Township, in Licking County (location 5), where it has a thickness of 3 to 4 feet or less and is estimated to cover about 1,000 acres. This cannel has long been famous, probably in large part because before the discovery of oil in Pennsylvania it was distilled for oil in an extensive plant.

The coal is at the horizon of the Lower Mercer. Orton,[2] writing in 1884, estimated that only about 10 acres of coal had been mined out, notwithstanding the fact that it has been mined for 50 years. In the mine the cannel bench averaged about 3½ feet in thickness, being nowhere less than 3 feet and rising about 4 feet only in the main swamps. At that time the coal was being mined by bearing in at the top and then shooting the coal up with powder. The miner could get only 2 tons a day by hard work, for which he received a dollar a ton. The coal sold at the mouth of the mine for $1.80. If hauled to the railroad for shipping, the cost was increased by about a dollar. The cannel is described as curly and of excellent appearance, though high in ash. A shaft one-fourth of a mile east of the mine found 3 feet of good cannel. Two

[1] Orton, Edward, Ohio Geol. Survey Rept., vol. 5, Economic geology, pp. 843 et seq., 1884.

[2] Idem, p. 908.

miles to the east the cannel had a thickness of 2 feet 8 inches; 1 mile to the southeast 2 feet; and 2 miles to the southeast only 8 inches. (See fig. 6, section 22, and analyses 152–155, p. 26.)

JACKSON COUNTY.

In Milton Township, Jackson County (location 7), the Tionesta seam near the top of the Pottsville supplies some cannel of fair quality. (See analyses 149–151, p. 26.) The cannel portion ranges from 15 to 30 inches in thickness. It is overlain by 6 inches of shaly cannel and that in turn by 6 inches of bituminous coal. (See fig. 6, section 23.) Its extent has not been determined.[1]

HOLMES COUNTY.

In Holmes County both the Upper and Lower Mercer coals carry some cannel.[2] In Killbuck Township (location 3) cannel from the Upper Mercer is locally 7 to 9 feet thick (fig. 6, section 24). That from the Lower Mercer ranges from 2 feet thick to 2 feet 6 inches in several places. (See analyses 143–148, p. 26.)

SCIOTO COUNTY.

The Upper Mercer coal shows up to 20 inches of cannel at one or two points in Scioto County. The great coal of the Hocking Valley field (location 6) usually shows a few inches of bone coal 10 to 18 inches from the top. Locally this changes to cannel and in a few places reaches a maximum thickness of 10 inches and is of excellent quality. At Pioneer station a mine, the Webster, has 16 to 20 inches of cannel coal. A little cannel has been shipped from the Cook mine.[3]

JEFFERSON COUNTY.

One of the most interesting occurrences of cannel in the State is at the Diamond mine (location 2), in Jefferson County. The coal here comprises 3 to 9 feet of bituminous coal, the greater thickness occurring in the "swamps," where lower benches come in. Beneath this, covering about an acre or two, is a bed of cannel 5 inches in maximum thickness. From this small bed Newberry has collected more than 50 species of fishes and reptiles, strong testimony to the water origin of cannel coal.[4]

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[1] Orton, Edward, Ohio Geol. Survey Rept., vol. 5, Economic geology, p. 1032, 1884.
[2] Idem, p. 825.
[3] Idem, p. 1039.
[4] Idem, p. 212.

INDIANA.

Thin beds of cannel coal are found in several of the counties of this State, usually as benches on or in a bituminous coal bed. (See Pl. V, p. 56.)

DAVIESS COUNTY.

One basin of cannel coal of commercial thickness and extent occurs at Cannelsburg, Daviess County (location 2[1]).

The bed ranges in thickness from 6 feet to 2 feet 6 inches, an average being about 4 feet 8 inches, of which the top 3 feet 2 inches is cannel. (See fig. 7, sections 25–27.) The difference in thickness is mainly due to variation in the cannel, which lies in pockets in the bituminous coal, to which it adheres closely. Properly sampled analyses (19 and 20, p. 20) of this coal show 49.08 per cent of volatile matter, 26.35 per cent of fixed carbon, and 23.10 per cent of ash. Analyses of selected samples show 6 per cent or less of ash. Mining has shown this cannel coal to extend for at least a mile south of Cannelburg, and drillings indicate that the bed as a whole is of workable thickness over the better part of 6 square miles, though whether the cannel has that extent is not known. An opening 2 miles south of Cannelburg showed only 6 inches of cannel. This coal is Coal III of the State series, being, like so many cannel-bearing coals, near the bottom of the coal series.[2]

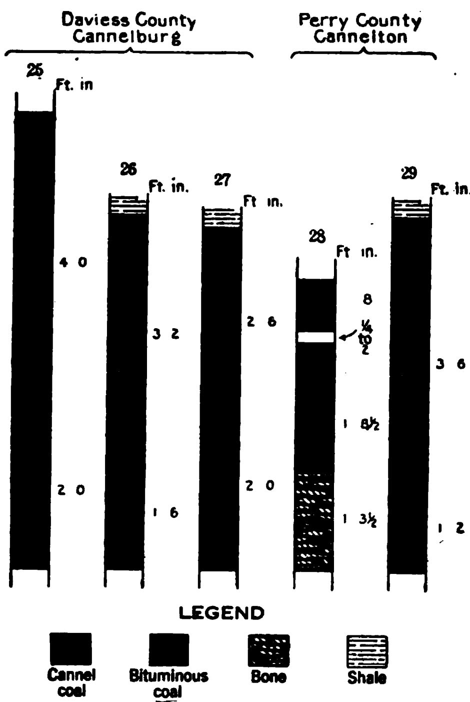

FIGURE 7.—Sections of cannel coal in Indiana.

PERRY COUNTY.

At Cannelton (location 1), in Perry County, on Ohio River, a coal has long been mined that might well be classed as a semicannel.

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[1] Locality numbers for Indiana appear on Plate V, p. 56.

[2] Cox, E. T., Indiana Geol. Survey Third and Fourth Ann. Repts., pp. 25 et seq., 1872. Ashley, G. H., Indiana Dept. Geology and Nat. Res. Twenty-third Ann. Rept., pp. 90 et seq., 1899.

It is dense and hard and breaks in any direction with conchoidal fracture. Analyses 22 and 23 (p. 20) show that it contains 42 per cent of volatile matter, 45 per cent of fixed carbon, and 6 per cent of ash. It lies in dish-shaped basins, thinning out entirely on the rise and thickening to 4 feet in the basins.[1] (See fig. 7, sections 28–29.)

PARKE COUNTY.

Above the narrows of Sugar Creek, in the northeast corner of Parke County, cannel coal outcrops on what was the Newlin place, 2 miles north of Bethany (location 3). An analysis (21) is given on page 20. Two blocks of cannel of nearly half a ton each are reported as having been taken to Indianapolis from here, but when visited by the writer in 1897 only 6 inches of cannel coal could be found.[2]

ILLINOIS.

Cannel coal is found in Illinois in very small quantities only; as a rule it is found in lenses in association with bituminous coal. Two occurrences in northern Illinois have recently been described by Grout.[3] At Colfax, McLean County, in the Colfax Cooperative Coal Co.'s mine, a 6-inch bed of cannel coal underlies the bituminous coal. On one side of the shaft lenses of cannel coal having a maximum thickness of 10 inches lie above the bituminous coal but have a horizontal extent of only about 100 feet. At La Salle cannel coal occurs in thin, irregular lenses on top of the coal in the Matheissen & Hegeler mine in about a third of the territory opened. (See analyses 24, 25, p. 21.)

MICHIGAN.

Lane[4] has reported of the Michigan coals that they "seem to lean generally toward cannel coal." It is a common condition in Michigan to find 3 to 8 inches of bone coal, cannel coal, or slaty coal above the main bed. On Rifle River, sec. 3, T. 19 N., R. 4 E., are 10 feet of black shale and cannel coal. The analysis shows 35 per cent of volatile matter, 45 per cent fixed carbon, and 11.8 per cent of ash. The thickness of the "cannel" is not stated.[5] Cannel coal occurs on top of the Saginaw bed at St. Charles and elsewhere.

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[1] Cox, E. T., Indiana Geol. Survey Third and Fourth Ann. Repts., pp. 95 et seq., 1872. Ashley, G. H., The coal deposits of Indiana: Indiana Dept. Geology and Nat. Res. Twenty-third Ann. Rept., pp. 1256 et seq., 1899.

[2] Idem, p. 320.

[3] Grout, F. F., Cannel coal in northern Illinois: Illinois State Geol. Survey Bull. 4, p. 198, 1907.

[4] Lane, A. C., Coal of Michigan: Michigan Geol. Survey, vol. 8, pt. 2, p. 19, 1902.

[5] Idem, pp. 91, 94, 105.

WEST VIRGINIA.

DISTRIBUTION OF THE COAL.

The prominent part played by West Virginia (then Virginia) in the cannel-coal industry of early days has already been noted. During the last 30 years commercial cannel-coal mining has been confined to six areas. (See Pl. V, p. 56, and fig. 9, p. 72.) Cannel-coal mining continued at the Wacomah mines on Paint Creek until the late eighties, the mines being abandoned before 1890. In mining at this point, however, the Lackawanna Coal & Lumber Co. still separates out the 15½-inch bench of cannel coal and sells it at double the price of the splint coal.[1] Cannel-coal mining continued at Cannelton until after 1900. The cannel-coal basin on Falling Rock Creek was reopened by the Falling Rock Cannel Coal Co., in the early nineties and was operated until 1910. In recent years mining has been by the Wierwick Cannel Co. Later mining began again at Mill Creek, at first by the Mill Creek Cannel Coal Co., which in 1910 changed to the Villa Cannel Coal Co., and subsequently to the Mill Creek Cannel Mining Co. During the nineties some cannel-coal mining was done in Wayne County by the Wells Branch Co.

Recently, according to mine inspectors' reports, cannel-coal mining has been revived at Peytona by the Peytona Block Coal Co. The section, as measured at this mine and as reported in the recent detailed report on Boone County, however, shows no cannel coal but 2 feet 9 inches of splint coal underlying 10 inches of block coal, from which it is separated by a 2-inch parting.[2] It is possible, however, that benches of cannel coal are separated out and marketed. The Sewall coal in the New River field very commonly carries a few inches of cannel coal or "cannelly" coal.

PRESTON COUNTY.

Cannel coal is reported to be carried by the Bakerstown coal at many points in the valley of Sandy Creek, in Preston County, probably at the horizon of the Lower Kittanning coal.[3] The Bakerstown coal also carries a little cannel at the C. N. Matlick place, three-tenths of a mile southwest of Marquess (section 30), where 15 inches of cannel overlies 9 inches of bituminous coal.[4]

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[1] Krebs, C. E., and Teets, D. D., Kanawha County: West Virginia Geol. Survey County Repts., p. 485, 1914.

[2] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., p. 262, 1915.

[3] White, I. C., The Appalachian coal field: West Virginia Geol. Survey, vol. 2, p. 297, 1903.

[4] Hennen, R. J., and Reger, D. B., Preston County: West Virginia Geol. Survey County Repts., p. 139, 1914.

BARBOUR COUNTY.

Three feet of cannel coal (fig. 8, section 31) is reported at the Lower Kittanning horizon at Moatsville, on Valley River (location 4[1]), just below the mouth of Teter Creek.[2]

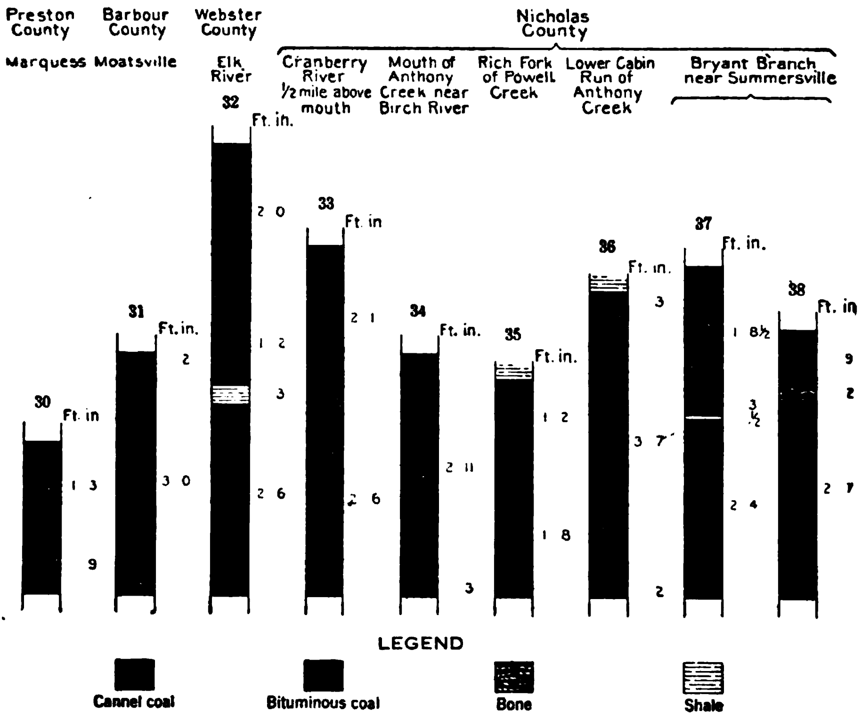

FIGURE 8.—Sections of cannel coal in Preston, Barbour, Webster, and Nicholas counties, W. Va.

UPSHUR COUNTY.

"Cannel slate" is reported from several places in Upshur County. Whether these beds will yield oil on distillation may be doubted on account of their easterly position in the coal field; they may, however, be noted for further investigation. The upper 2 feet of a coal bed at the crossing of the Coal & Coke Railway and Buckannon River (location 4) is described as "cannel slate."[3] Still farther east (location 5) on the same railroad, 2½ miles from the crossing of Mill Fork River,[4] is several feet of cannel shale.

[1] Location numbers for Preston, Barbour, and Braxton counties, W. Va., appear on Plate V (p. 56).

[2] White, I. C., The Appalachian coal field: West Virginia Geol. Survey, vol. 2, p. 297, 1903.

[3] White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2(A), p. 486, 1908.

[4] Idem, p. 518.

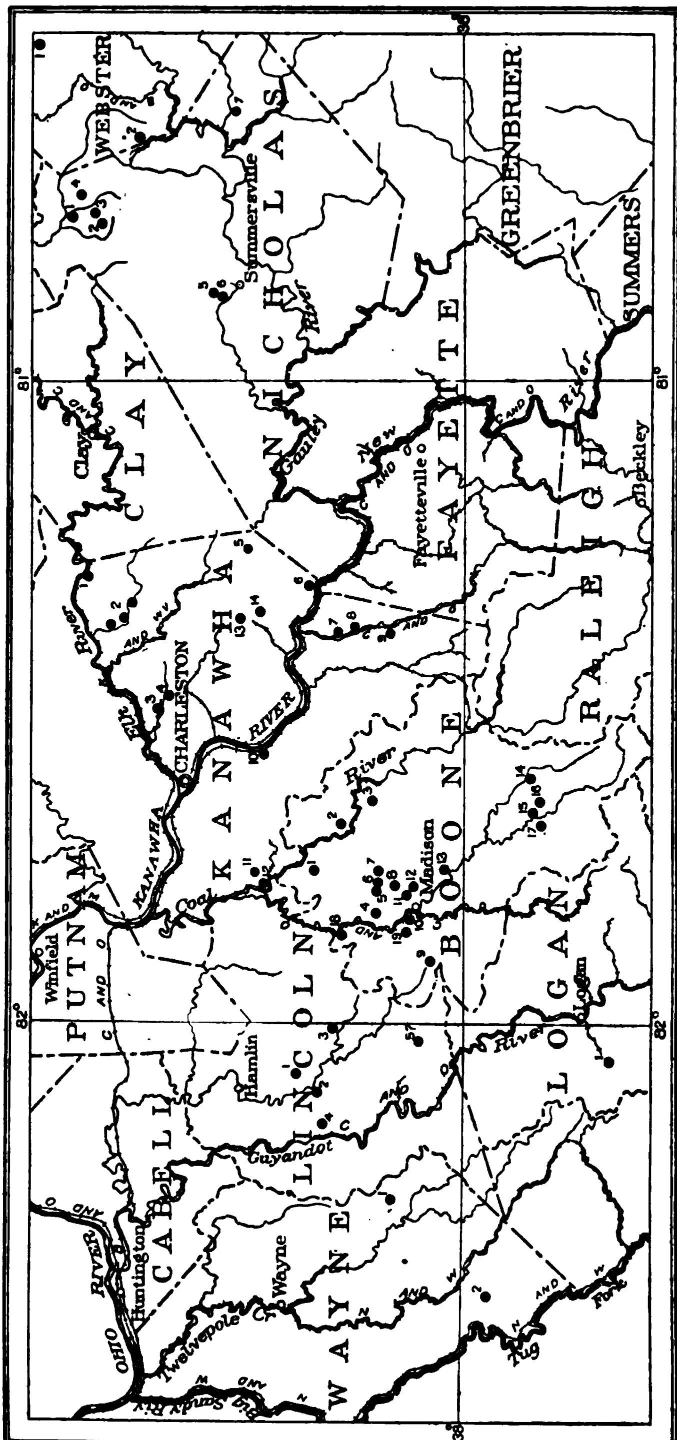

FIGURE 9.—Map of part of West Virginia showing position of cannel-coal deposits.

BRAXTON COUNTY.

At the falls of the Little Kanawha, in Braxton County (location 3), are reported two beds of cannel shale, each 2 feet thick, separated by 5 feet of shale. Whether these are low enough in ash to be used for oil production is not known.[1] Twenty inches of "cannel slate" occurs at the top of the Stockton coal at the forks of Wolf Creek, 3 miles above the mouth, near the James Wyatt place.[2]

WEBSTER COUNTY.

Two feet of impure cannel coal capping a thick bed of bituminous coal (fig. 8, section 32) is found in Webster County (see fig. 9) at the head of Coal Spring Hollow (location 1[3]), from which a small branch flows to Elk River one-fourth of a mile above the mouth of Big Run, 6 miles below Webster Springs.[4] A very similar section of cannel is found at the head of Stroud Creek (location 2), 5 miles north of Camden, on Gauley River, and has been observed on Laurel Creek and Elk River.[5] Fourteen inches of shaly cannel occurs in the Eagle coal on Grassy Run, a branch of the right fork of Holly River.[6]

NICHOLAS COUNTY.

Two feet of cannel coal over 30 inches of bituminous coal (fig. 8, section 33) occurs on the south side of Cranberry River 1½ miles above the mouth (location 7). The top of the coal grades into the black shale of the roof.

An extensive pocket of cannel appears to lie south of Birch River between Powell Creek and Poplar Creek. At the mouth of Anthony Creek, 1½ miles above Birch River post office and 400 feet above the valley (location 1), on the Scott place, is a 3-foot bed of cannel (fig. 8, section 34). Farther south a bed of cannel coal, at possibly this same horizon, is reported as 4 feet thick (fig. 8, section 36) on lower Cabin Fork of Anthony Creek (location 3). It appears to run through the ridge to the west, showing 20 inches of cannel (fig. 8, section 35) on Rich Fork of Powell Creek (location 2). In

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[1] White, I. C., The Appalachian coal field: West Virginia Geol. Survey, vol. 2, p. 449, 1903.

[2] White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2 (A), p. 483, 1908.

[3] Location numbers for Webster, Nicholas, Kanawha, Boone, Lincoln, Logan, and Wayne counties, W. Va., appear on fig. 9; a fresh set is begun for each cannel-bearing county.

[4] White, I. C., The Appalachian coal field: West Virginia Geol. Survey, vol. 2, p. 365, 1903.

[5] Idem, p. 367.

[6] White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2 (A), p. 343, 1908.

the ridge east of Anthony Creek the same bed is reported on the John Dodrill place on Poplar Creek as 3 feet thick with some cannel (location 4). Two miles southwest of Summersville on Brant Run is a bed of coal showing at one place (location 5) 20½ inches of shaly cannel above 30 inches of bituminous coal (fig. 8, section 37) and at another place, half a mile nearer Summersville (location 6), 9½ inches of cannel over 37 inches of bituminous coal (fig. 8, section 38).

KANAWHA COUNTY.

Queen Shoals.—A layer of cannel coal is found in rolls, and only in rolls, at the Queen Shoals Co.'s No. 1 mine (location 1).[1] An analysis (183) is given on page 28.

Falling Rock.—Falling Rock (location 2) has long been the seat of cannel-coal mining (p. 51). Before the war a little distillery 1½ miles above the mouth of Falling Rock Creek was operated with cannel coal mined near by. Mining has gradually extended up the creek, and recently reached 6 miles or more from the mouth. Where mined in recent years the bed, known as the No. 5 block, consists of two benches of 8 and 20 inches, separated by 5 inches of shale. (Pl. VI, section 39.) The coal in the mine is reported to average from 2 to 2½ feet and to reach a maximum of 6 feet.[2]

Villa.—Cannel-coal mining has been in progress on Mill Creek since some time before the war. The Villa Coal Mining Co. is now operating at Villa (location 3), where the No. 5 block coal bed has a total thickness of 4 feet 7 inches, of which the top 2 feet 2 inches and the bottom 11 inches are glossy block cannel. The 1 foot 4 inches just above the shale partings is a bird's-eye cannel. (Pl. VI, section 40.) An analysis (184, p. 28) of the coal here shows 10 per cent of ash and 45 per cent of volatile matter.[3] A section (Pl. VI, section 41) half a mile southeast of Villa (location 4) shows 3 feet of cannel separated from 2 feet of bituminous coal by 7 feet of sandstone.[4]

Pond Gap.—A mile southeast of Pond Gap, on Bell Creek (location 5), is a 2-foot bed of cannel (Pl. VI, section 42) on the G. W. Ramsay place. Ten feet lower is a 4-foot bed of bituminous coal.

Mammoth.—I. C. White[5] measured a section of No. 5 block coal on the left fork of Kelly Creek above Mammoth (location 13) and

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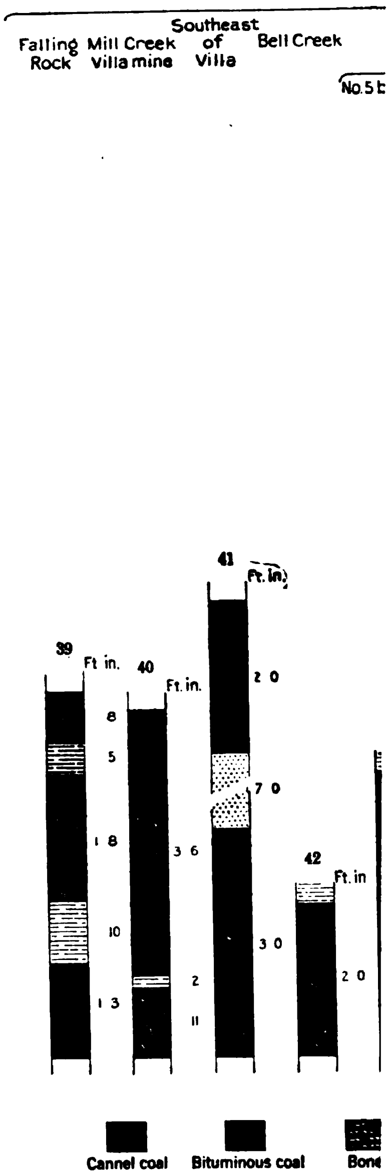
[1] Krebs, C. E., and Teets, D. D., Kanawha County: West Virginia Geol. Survey County Repts., p. 439, 1914.

[2] Idem, p. 441.

[3] Idem, p. 428.

[4] Idem, p. 189. See also White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2 (A), p. 547, 1908.

[5] White, I. C., op. cit., p. 548.


Falling Rock
Mill Creek Villa mine
Southeast of Villa
Bell Creek
No.5 b
39
Ft in.
8
5
1 8
10
1 3
40
Ft. in.
3 6
2
11
41
Ft. in.
2 0
7 0
3 0
42
Ft. in
2 0
Cannel coal
Bituminous coal
Bone

SECTIONS (

found it to contain 18 inches of shaly cannel over 6 inches of cannel shale below 39 inches of bituminous coal. A little south of this, about 2 miles above the mouth of Fivemile Branch of Kelly Creek (location 14), a bed containing 22 inches of fair cannel coal and 23 inches of bituminous coal has been opened.[1]

Cannelton.—Mining by the Cannelton Coal Co. was begun at an early date at Cannelton (location 6) and was continued until comparatively recent days. Cannel coal occurs here in both the No. 5 block (Pl. VI, section 43), which comes just above the Kanawha black flint (the key rock of the district), and in the Stockton coal (Pl. VI, sections 44, 45), which comes just below the black flint. According to sections by Edwards[2] the higher bed contained 40 inches of cannel overlain by 5 inches of bituminous coal, and the lower bed contained 3 feet of cannel overlain by nearly 3 feet of bituminous coal. The top of the bed was only 10 inches below the base of the black flint. (See analysis 184a, p. 28.)

Wacomah.—Wacomah (location 7) was long the site of extensive cannel-coal mining by the Kanawha Coal Co., and the cannel-coal bench is still being separated by the Lackawanna Coal & Lumber Co. (p. 70), which is operating at this point on the Coalburg bed. (See Pl. VI, sections 46, 47.) An analysis (185, p. 28) of the cannel shows 12 per cent of ash and 41 per cent of volatile matter.[3]

Standard.—At the opening of the Coalburg bed in the hill just east of Standard (location 8) there are 30 inches of cannel in a bed 6 feet 4 inches thick (Pl. VI, section 48).[4]

Detroit.—Still farther up Paint Creek, in the ridge just west of Detroit station (location 9), the Coalberg bed (Pl. VI, section 49) carries 26 inches of cannel coal.[4] The occurrence of cannel coal at this same horizon over so wide an area suggests the possibility that a large basin may be found on Paint Creek.

Marmet.—The Coalburg bed is also a cannel coal at the G. W. & N. A. Peel opening half a mile west of Marmet (location 10; Pl. VI, section 50), where it contains 3 feet 7 inches of coal separated into two benches by 2 feet 5 inches of shale.[5]

Lens Creek.—According to Lyman[6] several of the beds on Lens Creek (locations 13 and 14) carry cannel. The so-called "slate vein" carries 14 inches of cannel in a 3 foot 5 inch bed in Church Hollow, south of the mouth of the creek. The "Factory cannel-

[1] White, I. C., op. cit., p. 544.
[2] Edwards, W. S., Coals and cokes of West Virginia, pp. 48, 49, 1892.
[3] Krebs, C. E., and Teets, D. D., Kanawha County: West Virginia Geol. Survey County Repts., p. 485, 1914.
[4] Idem, p. 236.
[5] Idem, p. 476.
[6] Lyman, B. S., Some coal-measure sections near Peytona, W. Va.: Am. Philos. Soc. Proc., vol. 33, pp. 282–309, maps, 1894.

coal bed" is the one formerly worked at the old oil factory on Left Fork, where the section showed 2 feet 5 inches of cannel (only 1 foot 6 inches of which was good coal), overlain by 9½ inches of black clay and by 6 inches of bituminous coal. The same bed was opened again beside Nuby's house on Left Fork, where it showed 3 inches

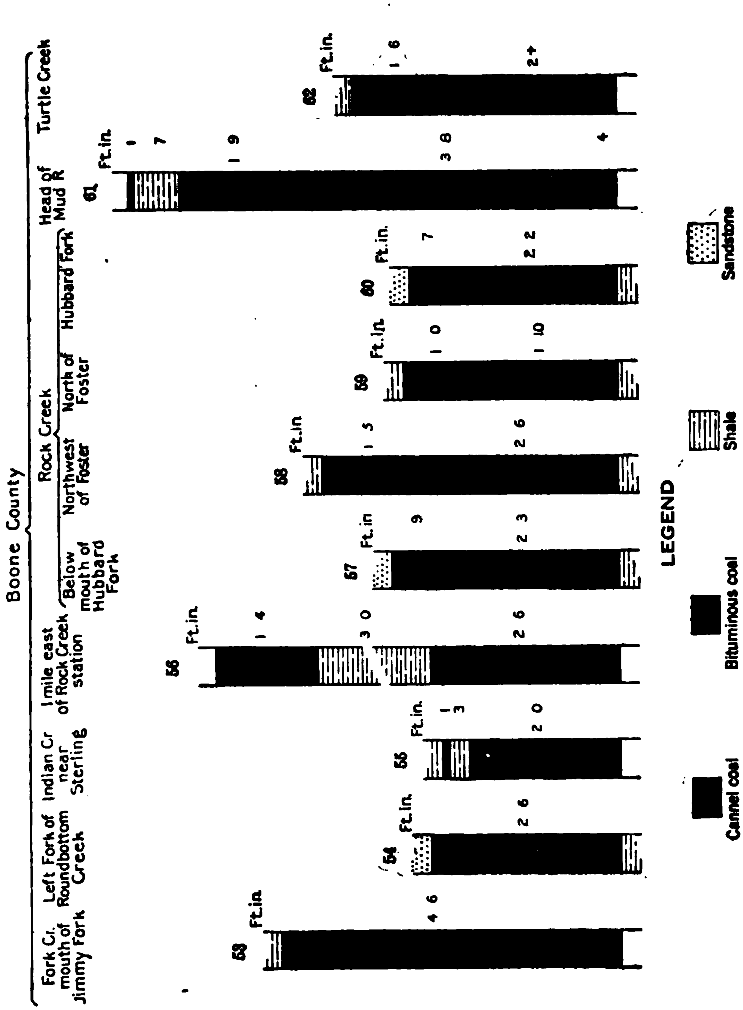


FIGURE 10.—Sections of cannel coal in part of Boone County, W. Va.

of poor cannel. Other sections of this coal bed gave only a few inches of cannel, the rest being good bituminous coal. Another bed, probably corresponding to the upper cannel at Peytona, is described as "a laminated cannel coal with thin seams of bituminous coal"; though having the analysis of a bituminous coal it mines out in large blocks like a cannel and is said to burn like a cannel.

Brounland.—At the Courtney & Brown opening near Brounland (locations 11 and 12), the Stockton-Lewiston bed has a thickness (Pl. VI, section 52) of 12 feet of coal with thin partings and carries 19 inches of impure cannel.[1] At the Burrville Keefer place, on Little "Barrier" (Brier?) Creek (Pl. VI, section 51), 3 feet of high-ash cannel (analysis 186, p. 28) overlies 30 inches of bituminous coal.[2] An old opening 60 feet above the No. 5 block coal shows cannel coal.

BOONE COUNTY.

The cannel-coal industry was extensively developed in Boone County in early days (p. 51). The center of the development was at Peytona, two of the mines being at that point, though a recent detailed report on this county[3] makes no mention of any cannel coal in the immediate area. A number of coal companies have been organized in this county for mining cannel coal.

Fork Creek.—A number of prospect openings have been made by the Fork Creek Coal Co. on Fork Creek (location 1), where the No. 5 block bed ranges from less than 2 to more than 6 feet. In one of these openings the bed is cannel, having a thickness of 4½ feet (fig. 10, section 53). This opening is opposite the mouth of Jimmy Fork, 3.8 miles south of Brounland.[4]

Roundbottom.—A number of openings on the Henshaw coal were recently made by the Boone & Kanawha Land & Mining Co. on Roundbottom (location 2) and adjoining creeks. One of these, on the left fork of Roundbottom, shows (fig. 10, section 54) 30 inches of cannel coal.[5]

Sterling.—An opening by the Hickory Ash Coal Co. (fig. 10, section 55) on Indian Creek near Sterling (location 3) has developed 2 feet of cannel coal.[6]

Peytona.—Information as to the old cannel-coal mines about Peytona was obtained from Lyman's report.[7] There were in this region two principal cannel-bearing beds known as the main cannel and the upper cannel. The upper bed measured 21 to 31 inches of smooth cannel at the Peytona mines. On Abshire Branch of Indian Creek, half a mile southeast of the Peytona mines, it carried 23 inches of cannel. Two hundred yards up the same branch in another

[1] Krebs, C. E., and Teets, D. D., Kanawha County: West Virginia Geol. Survey County Repts., p. 456, 1914.
[2] Idem, p. 421.
[3] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., 1915.
[4] Idem, p. 212.
[5] Idem, p. 340.
[6] Idem, p. 435.
[7] Lyman, B. S., Some coal-measure sections near Peytona, W. Va.: Am. Philos. Soc. Proc., vol. 33, pp. 282–309, 1894.

opening it showed only 15 inches of cannel. Back of John McCarty's house on Droddys Creek, in an opening made in June, 1872, it contained 38¾ inches of cannel. Above the blacksmith shop on the same creek it showed only 10½ inches of coal, nearly all bituminous.

The main cannel bed, which was worked from about 1852, carried 20 to 41 inches of cannel, and as much as 17½ inches in places at the bottom was curly, underlain here and there by bituminous coal with a maximum thickness of 8 inches. An opening on the river front three-fourths of a mile northeast of the mines showed only a few inches of cannel. In the Abshire Hollow, half a mile southeast of the mines, the bed comprises two benches of cannel, 3 inches and 10 inches thick, separated by 11 inches of bituminous coal. Tests of the Peytona cannel by the Manhattan Gaslight Co. of New York in 1869 gave a standard yield of 10,000 feet of 41-candlepower gas per long ton of coal, with a maximum yield of 13,200 cubic feet. The coal contained 49 per cent of volatile matter, 41 per cent of fixed carbon, and 13 per cent of ash.

Rock Creek.—A mile east of Rock Creek station (location 4) on Rock Creek, on the Samuel Cabell place, 16 inches of cannel coal associated with 30 inches of splint coal (fig. 10, section 56) is found. This bed appears to be part of an extensive basin of cannel that extends up Rock Creek above Foster and southward through the ridge toward Madison.[1] On the Jackson Darlow place on the north side of Rock Creek below the mouth of Hubbard Fork (location 5) the cannel is reported to be 2 feet 3 inches to 3 feet 8 inches thick, overlain with 9 inches of bituminous coal (fig. 10, section 57).[2] On the Samuel Carpenter place, northwest of Foster (location 6) this same coal, the Alma (fig. 10, section 58), carries 30 inches of cannel under 17 inches of splint coal.[3] Just north of Foster, on the William Holstein place (location 7), the cannel bed is 22 inches thick (fig. 70, section 59) and overlies 12 inches of splint coal.[3] On the J. A. Catley place (location 8), on the east side of Hubbard Fork of Rock Creek (fig. 10, section 60), the cannel is 22 inches thick and the splint 7 inches.

Madison.—Northeast of Madison (location 11) the Rock Creek cannel bed is 18 inches thick and the splint the same, separated by 1 foot of shale.[4]

Mud River.—At the Floyd Nelson mine, at the head of Mud River, 2 miles southwest of Turtle Creek (location 9), there is a fine showing of cannel coal. (See fig. 10, section 61.) Two analyses (177,

[1] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., p. 322, 1915.

[2] Idem, p. 405. White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2(A), p. 598, 1908.

[3] Krebs, C. E., and Teets, D. D., op. cit., p. 405.

[4] Idem., p. 406.

178, p. 27)[1] are so different as to suggest that one or the other sample was mixed with some other coal.

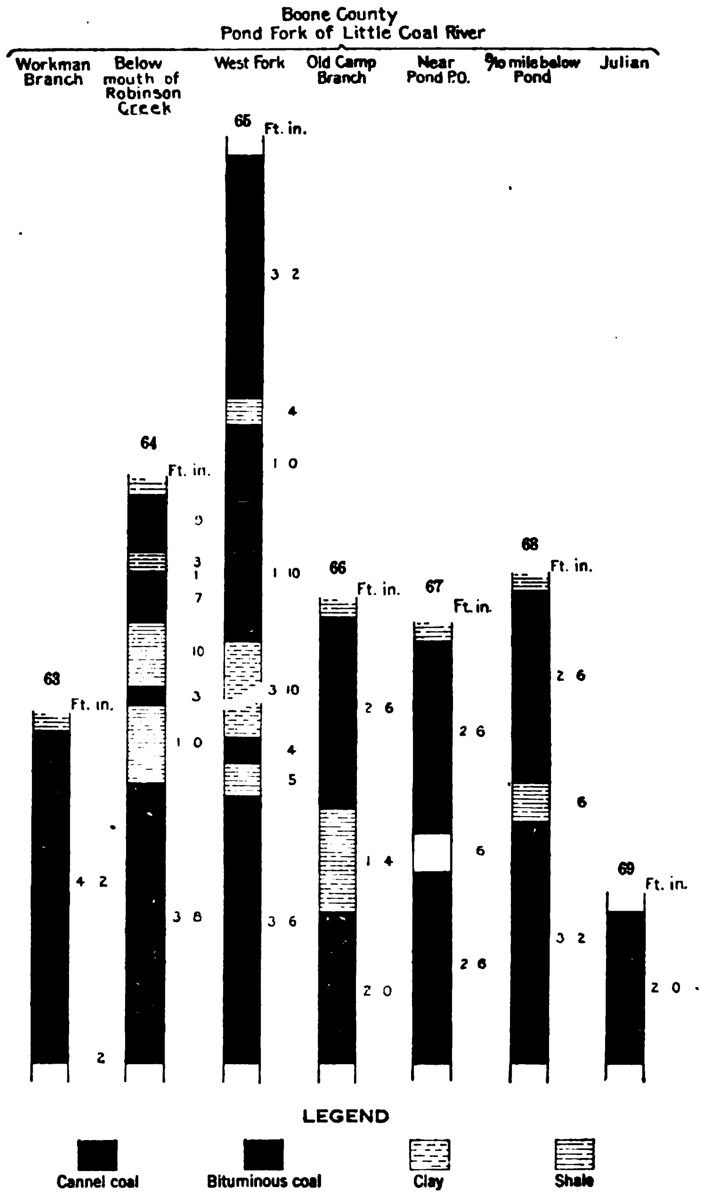


FIGURE 11.—Sections of cannel coal on Pond Fork of Little Coal River, Boone County, W. Va.

Turtle Creek.—The Alma coal carries cannel on either side of Turtle Creek at the J. C. Ballard openings. On the south side,

[1] Krebs, C. E., and Teets, D. D., op. cit., pp. 323–324, 575.

four-fifths of a mile southwest of Danville (location 10), 2 feet of cannel occurs (fig. 10, section 62), and on the north side of the creek on the same land (location 19) 15 inches of cannel was seen. The floor, however, was not reached in either section.[1]

Workman Branch.—Cannel coal has been noted 3 miles east of Madison on Workman Branch of Pond Fork (location 12), at the Bedford et al. opening (fig. 11, section 63). This is the Hernshaw coal and carries 50 inches of cannel. An analysis (180, p. 27) shows 12 per cent of ash and 51 per cent of volatile matter. This bed has not been opened at other points in this area, so its extent is not known. The coal was at one time hauled by wagon to Madison and there loaded on the cars for shipment.[2]

Pond Fork below Robinson.—About 5 miles above Madison on Pond Fork, half a mile below the mouth of Robinson Creek, on the W. P. Crafts place (location 13), there is a good cannel coal, 3 feet to 3 feet 8 inches thick (fig. 11, section 64). It appears to be the Williamson coal and it has long been mined for local use. An analysis (181, p. 27) shows about 12 per cent of ash and 47 per cent of volatile matter.[3]

West Fork.—On the west side of West Fork of Pond Fork at the mouth of James Creek, half a mile south of Chap post office (location 14), 22 inches of cannel (fig. 11, section 65) is found in the Winifrede coal on the land of E. J. Berwynd.[4]

Old Camp Branch.—The same bed shows 2 feet of cannel associated with 30 inches of bituminous coal (fig. 11, section 66) on the Wharton estate on Old Camp Branch (location 15), half a mile above the mouth.[5]

Pond post office.—On lands of the Wharton estate (location 16) just east of Pond[6] post office the cannel thickens to 30 inches (fig. 11, section 67). This bench of cannel is over 3 feet thick (fig. 11, section 68) on the east side of a small branch of Pond Fork (location 17), half a mile above the mouth of Old Camp Branch and nearly a mile northwest of Pond.[4] (See section 68.) An analysis (182) is given on page 27.

Julian.—Two feet of cannel coal (fig. 11, section 69) are reported at Julian on Little Coal River just south of the county line (location 18).[7]

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[1] Krebs, C. E., and Teets, D. D., Boone County: West Virginia Geol. Survey County Repts., p. 407, 1915.
[2] Idem, pp. 341–342.
[3] Idem, p. 374.
[4] Idem, p. 309.
[5] Idem, p. 304.
[6] Idem, p. 305.
[7] Krebs, C. E., and Teets, D. D., Cabell, Wayne, and Lincoln counties: West Virginia Geol. Survey County Repts., p. 146, 1913.

LINCOLN COUNTY.

Laurel Fork of Mud River.—The No. 5 block[1] coal opened at the John Smith place on Laurel Fork of Mud River (location 1) near Jenks post office, where it contains 18 inches of semicannel coal overlying 28 inches of block coal (fig. 12, section 70).

Mud River.—The No. 5 block coal opened on the Hiram Seites place on Mud River 4¼ miles from Midkiff (location 2), near Jenks,[2]

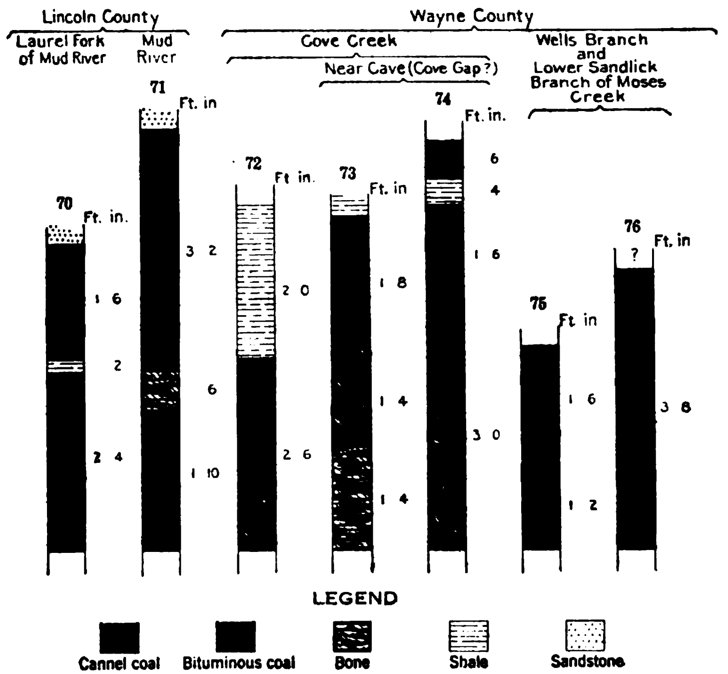


FIGURE 12.—Sections of cannel coal in Lincoln and Wayne counties, W. Va.

shows 22 inches of semicannel under 38 inches of block coal (fig. 11, section 71). An analysis (187b) is given on page 28.

Stinson Branch.—On Stinson Branch of the Left Mud, the lower Stockton coal carries 27 inches of cannel near Ed Simpson's (location 3).[3]

Big Ugly.—Four feet of cannel coal is reported on the land of J. C. Chapman, in the hills adjoining Big Ugly Creek (location 5), in the southeastern part of this county.[4]

[1] Krebs, C. E., and Teets, D. D., Cabell, Wayne, and Lincoln counties: West Virginia Geol. Survey County Repts., p. 190, 1913.

[2] Idem, p. 191.

[3] White, I. C., Supplementary coal report: West Virginia Geol. Survey, vol. 2(A), p. 481, 1908.

[4] Idem, p. 482.

LOGAN COUNTY.

Holden.—The Stockton bed near Holden, 4 miles above Logan (location 1), carries 3 feet of bony cannel in a total thickness of 12 feet 6 inches. Immediately above the cannel is 10 inches of bituminous coal and just below it is 2 feet of shale, underlain by 27 inches of coal.[1]

WAYNE COUNTY.

Cove Creek.—The No. 5 block coal contains 30 inches of cannel coal (fig. 12, section 72) at the Lucian Wylie opening on Cove Creek.[2] I. C. White[3] describes a section (fig. 12, section 73) near Cave (Cove Gap) post office in which the cannel portion of the bed is 16 inches thick and bony. Across the stream, however, this changes to 3 feet of good cannel (fig. 12, section 74).

From this point a narrow belt of cannel extends in a western direction nearly across Wayne County, being found on all of the main branches of Twelvepole. It is possibly identical with the Moses Fork cannel of Kentucky [West Virginia]. The belt varies much in width, but it is frequently 2 to 3 miles wide. While the cannel is sometimes absent, yet it is fairly persistent and seldom less than 20 inches in thickness, being generally of good quality, comparing favorably with the cannel from the Stockton coal horizon opposite Montgomery on the Great Kanawha.

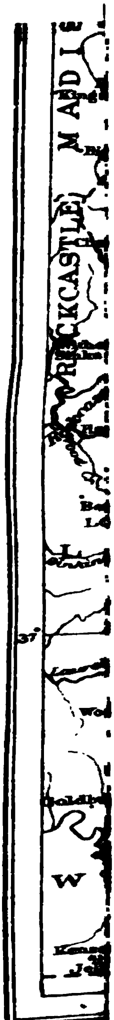
The recent detailed report on Wayne County[4] fails to mention or to give sections of such a belt of cannel except on Lower Sandlick Branch of Moses Creek (location 2), where 14 inches of cannel was measured. The cannel at this point was at one time mined by the Wells Branch Coal Co., the mine being located at Wells Branch but extending through the ridge to Moses Branch. Later the mine was sold to the Bradley Cannel Coal Co., which continued its development. The Bradley Cannel Coal Co. also opened another mine on the Stockton coal, which lies 100 feet lower and which at that point proved to be nearly all cannel (fig. 12, sections 75, 76).

KENTUCKY.

PRODUCTION.

Kentucky is the premier cannel-coal State of the Union. It has not only been the principal source of cannel in the past but it probably still contains the largest deposits of unmined cannel in the United States except those in Webb County, Tex. (See Pl. VII.)

[1] White, I. C., op. cit., p. 475.
[2] Krebs, C. E., and Teets, D. D., Cabell, Wayne, and Lincoln counties: West Virginia Geol. Survey County Repts., p. 218, 1913.
[3] White, I. C., The Appalachian coal field: West Virginia Geol. Survey, vol. 2, p. 543, 1903.
[4] Krebs, C. E., and Teets, D. D., op. cit., pp. 253–254.



Base f
map
A. F.

Nearly if not quite every county along the eastern border of the State has deposits of workable size, and some high-grade cannel has come from the western coal field. The following table shows the sources of the production during recent years:

Cannel coal produced in Kentucky, 1901–1910, in short tons.

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
Bell	7,348	6,293	6,022	1,136	....	....	....	....	....	1,298
Breathitt	....	....	648	255	....	....	....	....	830	39
Carter	11,203	11,309	8,341	2,780	5,306	2,384	2,440	....	2,742	....
Johnson	14,153	15,171	5,662	7,500	7,201	10,577	19,446	....	7,941	6,324
Morgan	3,067	32,353	46,314	52,492	73,603	50,051	51,800	....	59,485	68,447
Whitley	515	1,898	5,869	4,237	2,306	1,959	252	....	....	....
	36,287	67,056	72,856	68,400	88,416	64,971	73,938	70,413	70,998	76,108

GREENUP COUNTY.

Hunnewell.—Hunnewell (location 1) has long been a source of supply for cannel coal, which is mined from the ridge south of the station and east of Cane Creek. The coal is No. 3 of the Kentucky section or Lower Stinson of recent reports. The bed consists of three benches, of which the top and bottom are bituminous, each less than a foot thick, separated by a parting of bone or clay from the middle bench of cannel coal, which, as now exposed, has a thickness of only 14 to 16 inches (fig. 13, sections 77, 78). It is reported, however, to have had a thickness of 3 to 4 feet in the old workings. An analysis (71) is given on page 23. This coal was examined by Hislop, of the Paisley (Scotland) Gas Works (p. 40). As described by him, it is black, with considerable luster and yellowish-brown streak. The fracture is slaty, coarse, and partly semi-scaliform, with numerous impressions of stigmarias. The cross fracture inclines to conchoidal, with deposits of calcium carbonate, clay, and iron bisulphide (pyrite) under natural partings (joint planes). It is massive, compact, and very cohesive. On the fire it does not intumesce. The color of the ash is pale brown; it is well defined in stratification and is of very uniform composition and density.[1] Apparently the main body of cannel here has been removed, but a good acreage of thinner-bedded coal, like that shown in the columnar sec-

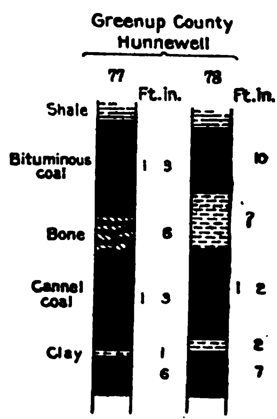


FIGURE 13.—Sections of cannel coal in Greenup County, Ky.

[1] Phalen, W. C., Economic geology of the Kenova quadrangle, Ky., Ohio, and W. Va.: U. S. Geol. Survey Bull. 349, p. 90, 1908.

tions, may still remain; or prospecting may reveal other minable bodies.[1]

Chinns Branch.—In the Kentucky Geological Survey report for 1858–59 an analysis of coal from Chinns Branch (location 2) is accompanied by the following description:[2]

Coal labeled "cannel coal sent by Col. L. G. Bradford, of Augusta; obtained from a bed about 4 feet 10 inches thick on the farm formerly owned by Levin Shreve, of Louisville, known as Fulton Forge, 3 miles above Greenupsburg and 1 mile from Ohio River, Greenup County, Ky. In large blocks not soiling the fingers cleaving in regular layers with no fibrous coal between them; of a jet-black color. In small portion more slaty with pyritous impressions of vegetable remains. Over the spirit lamp it softened and agglutinated somewhat but did not swell much.

(See analyses 72–74, p. 23, and report of tests, p. 14.)

The development of this tract of cannel coal was begun by the Maysville Manufacturing & Mining Co., in 1859, but the discovery of rock petroleum the same year broke up the enterprise. The cannel coal was described in a later report (with map) by Crandall,[3] as follows:

The cannel coal of workable thickness appears to be limited in this region to an area oblong in outline, having its axis along the line from the old Fulton mines near the landing to a point on Indian Run, in the East Fork Valley. How far beyond Indian Run and how wide the area of cannel coal of workable thickness is has not been fully determined, but it may reasonably be estimated at from 1,500 to 2,000 acres. Several hundred acres of this area, belonging to the Fulton tract, have already been worked out, as also several narrow points in the valley of Chinns Branch, on the Caroline tract; but the great body of coal, covering a considerable portion of the latter tract, remains to be mined. The best information obtainable as to the thickness on the old Fulton tract gives it an average of about 3 feet. Further up, on Chinns Branch, the bed has reached a thickness of 4½ feet. On Indian Run it is about 2 feet but superior to the thicker part for gas making. Like all cannel coals it will probably be found variable in thickness and quality in the working of the bed. On Indian Run the bed is accompanied by common bituminous coal, 1 foot on top and 6 to 8 inches below, making the whole bed about the same in thickness as the average on Chinns Branch, where the whole thickness is cannel.

CARTER COUNTY.

Boghead.—The Boghead coal is found on Upper and Lower Stinson creeks (location 1), 2 to 3 miles east of Grayson, the county seat, between Boghead (Afton post office) and Stinson. The coal has long been noted because of its extreme richness in oil, yielding under test 100 to 110 gallons of oil to the ton.[4] The cannel occurs in two

[1] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 65, 1910.

[2] Owen, D. D., Kentucky Geol. Survey Fourth Rept., p. 171, 1861.

[3] Crandall, A. R., Report on the Chinns Branch cannel-coal district: Kentucky Geol. Survey Repts. on the eastern coal field, C, pp. 5–6 [293–294], 1884.

[4] Owen, D. D., op. cit., pp. 111–114.

beds, Nos. 3 and 4 of the Kentucky section, or the Upper and Lower Stinson of recent reports.[1] The upper of the two coals is generally workable in this region but is mainly a splint and bituminous coal.

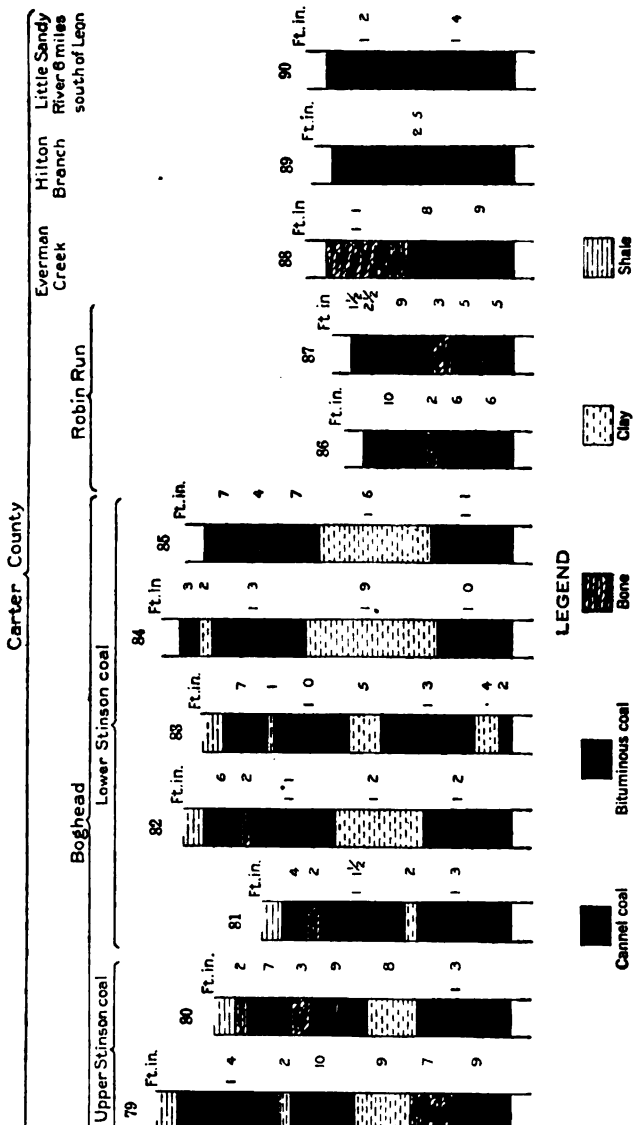


FIGURE 14.—Sections of cannel coal in Carter County, Ky.

In the Boghead area it contains an important bench of cannel coal which has been worked on Lower Stinson Creek by the Kentucky Cannel Coal Co. (fig. 14, sections 79–85). The old Lexington and

[1] Phalen, W. C., Economic geology of the Kenova quadrangle, Ky., Ohio, and W. Va.: U. S. Geol. Survey Bull. 349, pp. 85–92, 1908.

Carter Coal Mining Co. is said to have worked out a considerable territory southeast of the present workings.

The Lower Stinson coal, 30 feet below the Upper Stinson, is generally workable about Boghead. As at Hunnewell it is in three benches but is extremely variable, as is shown by the sections given. This coal is described by Hislop [1] as—

black and possesses a yellowish-brown streak and high luster. The fracture is slaty, coarse, and dull with impressions of stigmaria, while in the cross fracture it is conchoidal, with cuttings of fire clay on the natural partings [joint planes presumably]. It is very compact and cohesive. On the fire it partially and slightly intumesces. The color of the ash is brown. It is well defined in stratification and is of very uniform density.

Where weathered this coal splits into very thin leaves, some of which, measured by the writer, averaged about $\frac{1}{250}$ of an inch in thickness. Analyses (62–64) are given on page 22.

The Boghead cannel has been studied microscopically by David White.[2]

Robin Run.—The Lower Stinson coal has been opened at many places in the hills about Robin Run (location 3), 2 miles southeast of Grayson,[3] and at some of them cannel coal was found suggesting a possibly workable extension of the Boghead area (fig. 14, sections 86, 87).

Everman Creek.—What is probably a lower coal, opened on Barrett and Everman creeks (location 4), contains some cannel (fig. 14, section 88) in two benches.[4]

Hilton Branch.—On Hilton Branch of Little Fork of Little Sandy River (location 2), a few miles southwest of Willard, the Upper Stinson or No. 4 coal is in part cannel (with a reported thickness of 3 feet), overlain by a foot of bituminous coal. It has been found on the Elijah Sturgill and William Corey places, on the latter of which the cannel part of the bed has a maximum thickness of 29 inches (fig. 14, section 89). The cannel coal was not seen north or south of Hilton Branch.

Little Fork of Little Sandy River.—According to Hendrie [5]—

One of the most valuable deposits in this county, however, is found 4 miles northeast of Willard Station * * * and 6 miles southwest of Leon Station, * * * lying on the waters of the Little Fork of the Little Sandy River. The cannel blocks vary in thickness from 10 to 32 inches. An average section,

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[1] Phalen, W. C., op. cit., pp. 89–90.

[2] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, pp. 252–253, 1913. Owen, D. D., Kentucky Geol. Survey Fourth Rept., pp. 111, 114, 1861. Phalen, W. C., op. cit., pp. 85–92.

[3] Phalen, W. C., op. cit., pp. 87–89.

[4] Idem, pp. 88–89.

[5] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 146, 1894.

taken from an average of 21 measurements, shows a bed section as follows: Bituminous coal, 1 foot 2 inches; cannel coal, 1 foot 4 inches. [See fig. 14, section 90.]

The quality of this coal is shown by the analysis (No. 67, p. 22).

ELLIOTT COUNTY.

Ison Creek.—In the area between the Little Sandy and Little Fork the No. 6 bed or Winslow coal carries some cannel. In the ridge between Ison and Creechs creeks (location 2) it has been opened at several places. On the Andrew Stevens land, on the Creechs Creek side, it shows 40 inches of cannel over 3 inches of splint coal.[1] Similar showings occur on the Ison Creek side on the Thomas Caldwell and Isom Ison land. One section, measured by the writer, at the head of Ison Creek showed 32 inches of cannel.[2] (See fig. 15, sections 91, 92.)

Bruin Creek.—Two miles north of the last locality, on Greasy Run between Bruin Creek and the left fork of Brush Creek (location 1), the Winslow bed (fig. 15, section 93) shows 24 to 30 inches of cannel.[3] The coal here appears to contain considerable ash.

Sarah.—At Sarah a 12-inch bench of cannel coal lies at drainage level, 8 inches below the top of a 28-inch bed of bituminous coal. (See Pl. I, *A*.)

LAWRENCE COUNTY.

Torchlight.—In the Torchlight area (location 1) is the bed known as the "little cannel," the name being derived from a bed of cannel 3 to 6 inches thick in the middle of the coal. The "little cannel" has been opened near the head of Threemile Creek and at one time was mined and shipped over the Chatteroi Railroad. It is of interest because of this and of the further fact that specimens were sent to the World's Columbian Exposition, where an analysis (98, p. 24) was made. (See also analysis 99.) The bed has also been tested by Hislop, who reports "this is an excellent cannel coal."[4]

JOHNSON COUNTY.

Whitehouse.—Cannel coal has long been mined at Whitehouse[5] (location 1). The cannel bed is 18 to 20 inches thick and underlies 18 inches of bituminous coal (fig. 15, section 94). Analyses (89, 89a) are given on page 23.

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[1] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 74, 1910.

[2] Phalen, W. C., op. cit., pp. 102–103.

[3] Crandall, A. R., op. cit., p. 75.

[4] Phalen, W. C., op. cit., p. 59.

[5] Crandall, A. R., Kentucky Geol. Survey Bull. 4, p. 28, 1905.

Georges Creek.—Cannel coal on Georges Creek (location 6), Johnson County, is referred to by Crandall.[1]

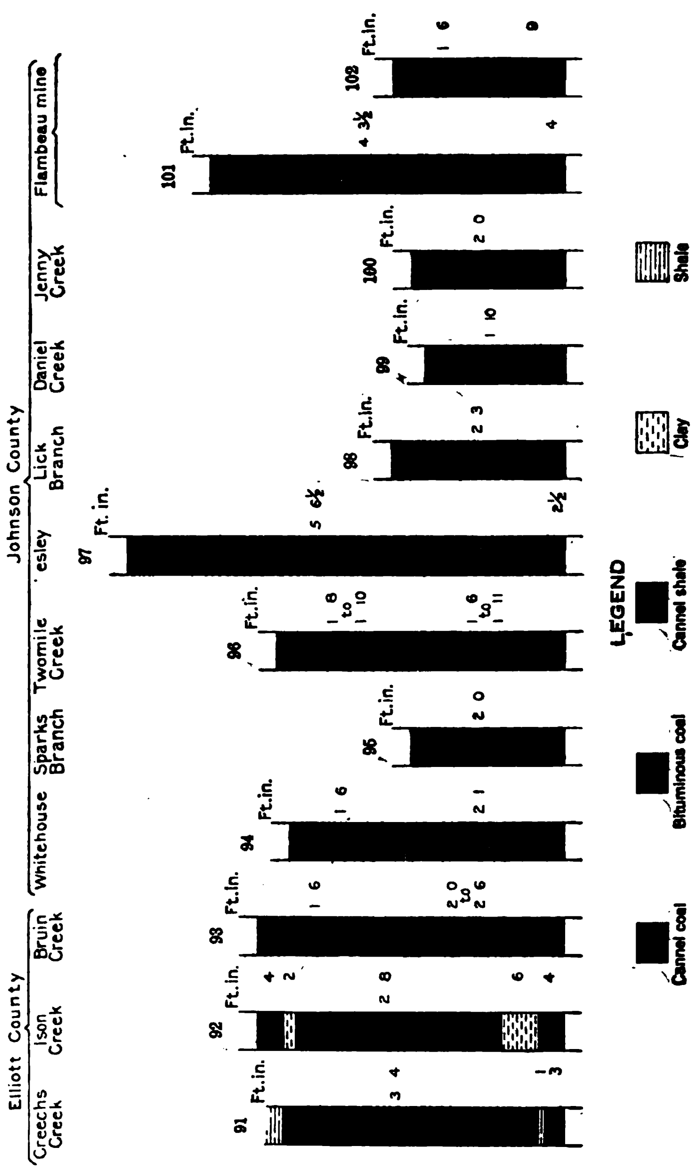

FIGURE 15.—Sections of cannel coal in Elliott and Johnson counties, Ky.

Sparks Branch.—On Sparks Branch (location 1) of Right Fork of Greasy Creek[2] the Whitehouse coal shows 2 feet of slaty cannel (fig. 15, section 95).

[1] Crandall, A. R., Preliminary report on the geology of Morgan, Johnson, Magoffin, and Floyd counties: Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [329], [1880].
[2] Crandall, A. R., Kentucky Geol. Survey Bull. 4, p. 34, 1905.

Twomile Creek.—Cannel coal has been mined[1] on Twomile Creek (location 3) by the Sandy River Coal Co. and carried by tramroad to the Chesapeake & Ohio Railway at Ward. The bed shows 18 to 23 inches of good cannel (analysis 90, p. 23), overlain by 20 to 22 inches of bituminous coal (fig. 15, section 96).

Lesley (East Point post office).—The Whitehouse bed has been mined in a high ridge at Lesley (location 4). (See fig. 15, section 97.) This coal has been described by David White[2] as follows:

> At the mine of the East Kentucky Coal Co. at Lesley the coal measures 5 feet 9 inches at the point where the sample exhibited at the Jamestown Exposition was mined. The basal layer, about 2½ inches in thickness, is a very pure coal, partly bituminous and speckled, showing that the more typical cannel-forming conditions did not obtain until some time after the beginning of coal formation at this point. Above this basal bed the cannel continues to the top, save an interruption by 4 inches of stratified and somewhat laminated coal about 2½ feet above the base. The roof is a rather gritty gray shale, with water-worn stems and more or less comminuted, transported plant débris, all somewhat macerated.

The cannel is black, tough, and somewhat slabby, splitting up into uneven slabs 1½ to 5 or 6 inches in thickness and distinctly conchoidal in the oblique or vertical fractures. Occasional cuticles, mostly from stigmarias, are seen on the rather glassy and wavy bedding planes. Two analyses (91, 92), the latter quoted from Lord, are given on page 23.

Miscellaneous occurrences.—Crandall[3] mentions cannel coal on Toms Creek (location 7 ?), on Lick Branch, on Daniel Creek (location 8), and on Jenny Creek (location 5 ?). The Lick Branch cannel is given as 27 inches thick (fig. 15, section 98) and, as shown by the analysis, is a semicannel; that on Daniel Creek is 22 inches thick (fig. 15, section 99), and that on Jenny Creek is 24 inches thick (fig. 15, section 100).

Flambeau.—At the Flambeau mine (location 9) the cannel coal has a thickness of 1 foot 6 inches to more than 4 feet 3 inches and overlies 4 to 6 inches of bituminous coal (fig. 15, sections 101, 102). The cannel is described as clean, carrying no impurities. Lord[4] gives the analyses (93 and 94) quoted on page 23.

MORGAN COUNTY.

For many years Morgan County has been the principal source of cannel coal in the United States. Kentucky (pp. 52–53) has long produced nearly as much cannel coal as all the other States combined,

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[1] Crandall, A. R., Kentucky Geol. Survey Bull. 4, pp. 34–35, 1905.

[2] White, David, and Thiessen, Reinhardt, The origin of coal: Bur. Mines Bull. 38, pp. 44, 253–256, 1913.

[3] Crandall, A. R., Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [329], [1880].

[4] Lord, N. W., and others, Analyses of coals in the United States: Bur. Mines Bull. 22, pts. 1 and 2, pp. 104, 540, 1913.

and Morgan County has produced more cannel coal than all of the other counties of the State combined. Most of this coal is found near the south edge of the county in the district around Cannel City.

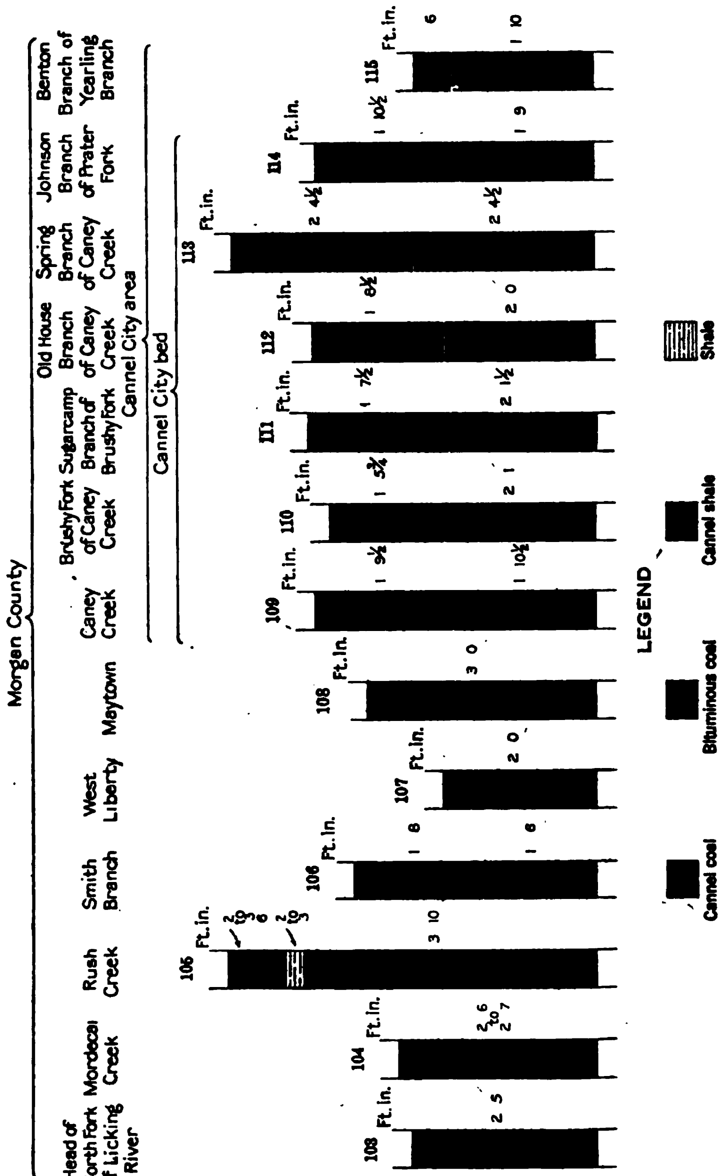

FIGURE 16.—Sections of cannel coal in Morgan County, Ky.

North Fork.—A large body of cannel appears to lie between the head of North Fork of Licking River and Elk Fork (locations 1, 2, and 3). It has been mined commercially by the North Fork Cannel

Coal Co. at Wrigley. It has been exposed at the head of the main fork (location 1), on Mordecai Creek (location 2), on Rush Creek (location 3), on Smith Branch, and on part of Lick Creek, and it may extend from Rush Creek through the ridge to the head of Straight Creek. Its thickness on main North Fork ranges from 29 to 39 inches or more (fig. 16, section 103). On Lick Creek its thickness is about 20 inches and at Mordecai Creek from 30 to 31 inches (fig. 16, section 104). Rush Creek openings show a greater thickness (fig. 16, section 105), ranging from 34 inches at the lower forks to 46 inches or more a half mile up the ravine on the right side.[1] Other measurements on Mordecai Creek give up to 36 inches and on Rush Creek up to 58 inches.[2]

Smith Branch.—The cannel coal has been opened[3] on Smith Branch of Open Fork of Paint Creek (location 4), half a mile above the mouth, showing 18 inches of cannel overlain by 20 inches of splint coal (fig. 16, section 106).

West Liberty.—Cannel coal, 18 to 24 inches thick (fig. 16, section 107), has been mined for local supply at West Liberty on the Cox and Cecil places in the ridge between Licking River and Caney Creek[4] (location 10).

Spaws Creek.—On Spaws Creek (location 11), which enters Licking River just above West Liberty, a bed of cannel is reported by Crandall[5] to be 18 inches thick.

Maytown.—Three feet of cannel coal (fig. 16, section 108) is reported by Crandall[5] to have been found on the Pierat place, east of Maytown (Blackwater of the older maps) (location 9). An analysis (115) is given on page 24.

Cannel City.—Cannel City (locations 5, 6, 7, 8, 12, and 13) is the center of what is probably the most extensive cannel-coal mining in the United States, and the area of the coal (fig. 17) is the most extensive yet developed in the State.

The coal, which is a semicannel, as shown by the analyses (116–124, pp. 24–25), has been mined commercially by the Kentucky Block Cannel Coal Co. and the Watson Cannel Coal Co., of Cannel City, the Gish Cannel Coal Co., of Piedmont, and the Bigstaff Cannel Coal Co., of Bigstaff. Crandall[6] gives sections of the coal as follows (see fig. 16):

Caney Creek, drift 3, above the mouth of Prater Fork, coal 44 inches, of which 22½ inches is cannel (section 109). Brushy Fork

[1] Crandall, A. R., Kentucky Geol. Survey Bull. 10, pp. 6–8, 1910.
[2] Crandall, A. R., Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [329], [1880].
[3] Crandall, A. R., Kentucky Geol. Survey Bull. 10, p. 12, 1910.
[4] Idem, p. 15.
[5] Crandall, A. R., Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [329], [1880].
[6] Crandall, A. R., Kentucky Geol. Survey Bull. 10, pp. 13–14, 1910.

of Caney Creek, Isaac Lykins place, coal 42¾ inches, of which 25 inches is cannel (section 110). Sugarcamp Branch of Brushy Fork of Caney Creek, coal 45 inches, of which 25½ inches is cannel (section 111). Old House Branch of Caney Creek, Will Ferguson place, coal 44½ inches, of which 24 inches is cannel (section 112). Drift 11, on Spring Branch of Caney Creek, coal 57 inches, of which 28½

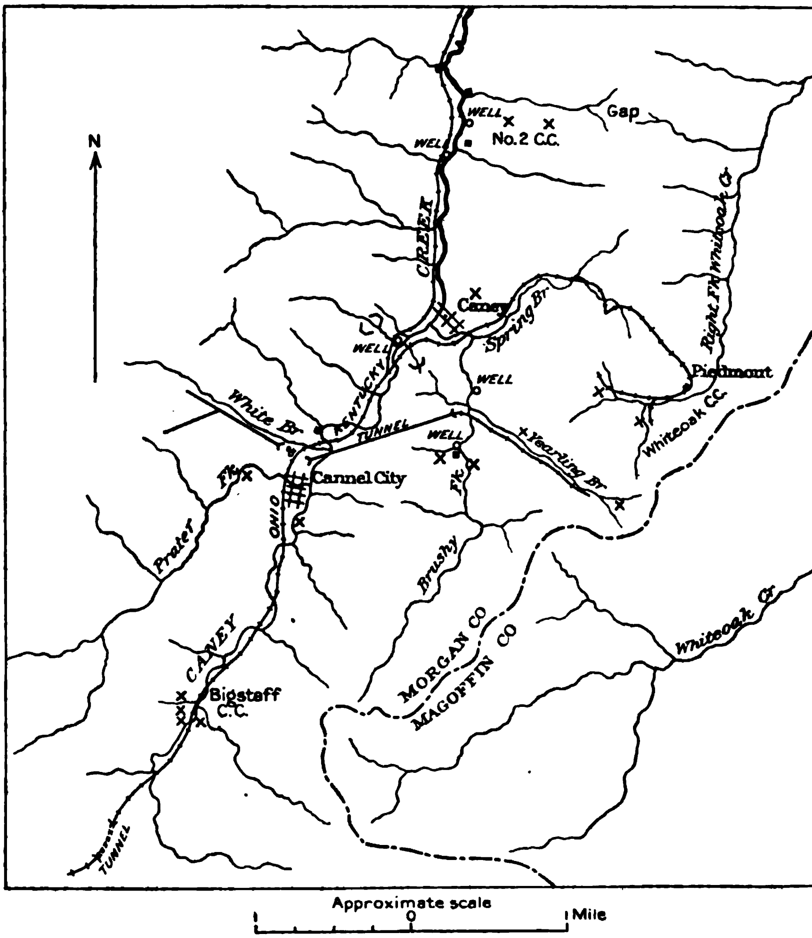

FIGURE 17.—Sketch map of cannel-coal area around Cannel City, Morgan County, Ky. (After Crandall, Kentucky Geol. Survey Bull. 10, p. 12.)

inches is cannel (section 113). Johnson Branch of Prater Fork of Caney Creek, north side, coal 43½ inches, of which 21 inches is cannel (section 114). The analyses (116–121, pp. 24–25) show these coals to have about 40 to 41 per cent of volatile matter and 48 to 51 per cent of fixed carbon.

About 200 feet above the main coal is an upper bed measuring 28 inches, of which 22 inches is a true cannel (section 115). (See

analysis 124, p. 25.) This upper coal, however, is limited to comparatively small pockets on the head of the right fork of White Oak Creek and Brushy Fork of Caney Creek and to an undeveloped area on the Frozen Creek side.[1]

MAGOFFIN COUNTY.

Colvin mine.—Cannel coal reported to be 3 feet in thickness (fig. 18, section 117) has been opened on the Colvin place (location 1), on Licking River just above the mouth of Johnson Creek.[2] An analysis (No. 110) is given on page 24.

Salyersville.—Near Salyersville (locality 3) a cannel-coal bed containing 14 inches of cannel coal (analysis 109, p. 24) lies below 18 inches of bituminous coal, the two being separated by a parting (fig. 18, section 118).[3]

Lykins.—Eighteen inches of cannel coal is reported on Licking River in this county, at the Lykins place, the exact location of which is not known.[3]

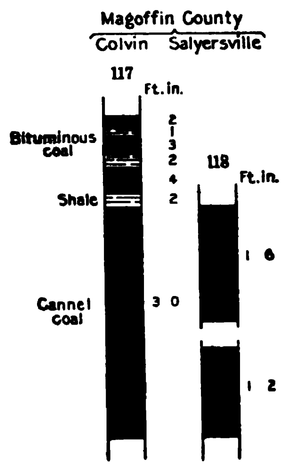

FIGURE 18.—Sections of cannel coal in Magoffin County, Ky.

WOLFE COUNTY.

Stillwater Creek.—Cannel coal (analyses 139, 140, p. 26) is mentioned as found on the John Murphy place on Stillwater Creek (location 1).[4]

PIKE COUNTY.

Brushy Fork.—Near the top of the ridge between Thompson Branch of Brushy Fork (location 1) and Upper Branch of John Creek a coal bed 52 inches thick contains 16 to 17 inches of cannel coal (fig. 19, section 121). On Left Fork of Brushy Fork what is probably the same bed (fig. 19, section 122) contains 27 inches of cannel coal.[5]

Little Brushy Branch.—A little cannel coal (fig. 19, section 123) is reported on Little Brushy Branch of John Creek (location 2), as shown in the section.[6]

Money Branch of Turkey Creek.—Cannel coal exists on Money Branch of Turkey Creek (location 3), being 17½ inches thick on the left fork and 22 inches thick on the right fork. (See fig. 19, sections 119, 120.) On the left fork the cannel bench is separated by 4 inches

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[1] Crandall, A. R., Kentucky Geol. Survey Bull. 10, pp. 13–14, 1910.
[2] Idem, p. 18.
[3] Crandall, A. R., Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [329], [1880].
[4] Crandall, A. R., Kentucky Geol. Survey Bull. 10, p. 58, 1910.
[5] Crandall, A. R., Kentucky Geol. Survey Bull. 4, p. 87, 1905.
[6] Idem, p. 48.

of black shale and coal from a bench of semicannel 2 feet thick, which has a 2½-inch parting near the middle. On the right fork the lower bench is all bituminous coal, 21 inches thick.[1]

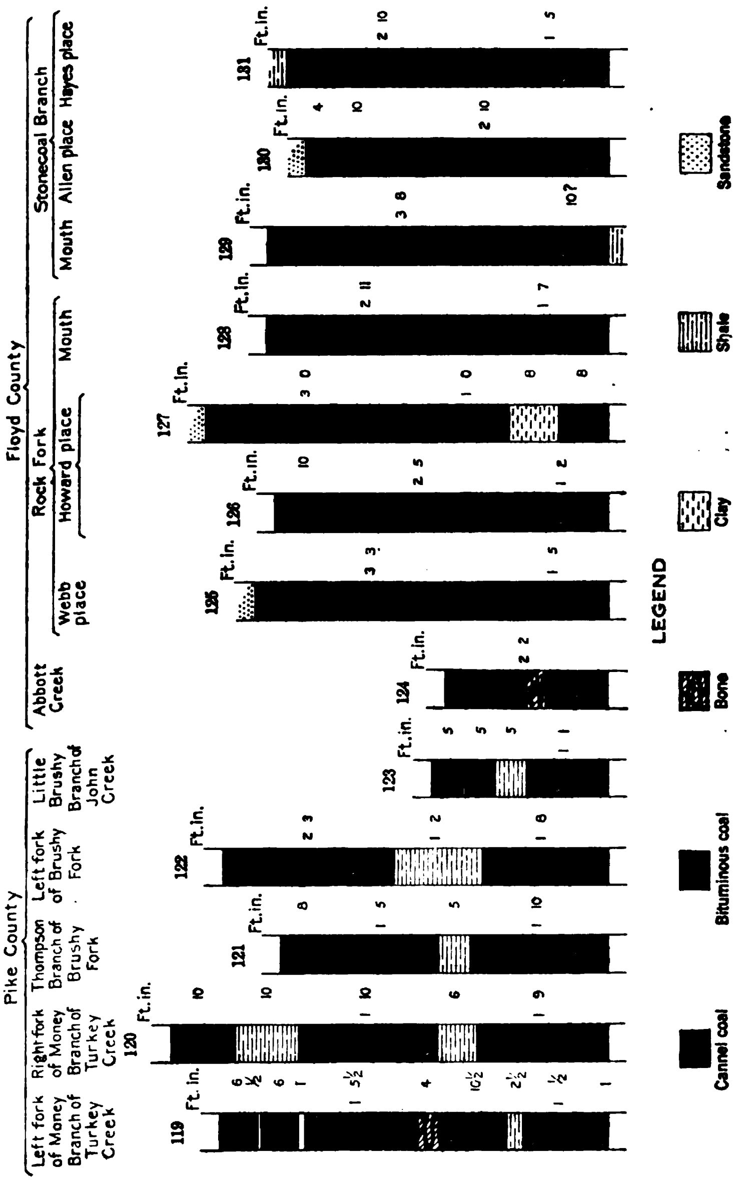

FIGURE 19.—Sections of cannel coal in Pike and Floyd counties, Ky.

FLOYD COUNTY.

Abbott Creek.—Crandall[2] reports 26 inches of cannel coal on Abbott Creek (location 1). (See fig. 19, section 124.)

[1] Hoeing, J. B., Kentucky Geol. Survey, 4th ser., vol. 1, pt. 1, p. 280, 1913.
[2] Crandall, A. R., Kentucky Geol. Survey, 2d ser., vol. 6, pt. 5, p. 15 [829], [1880].

Rock Fork of Right Fork of Beaver Creek.—Cannel coal has been opened at a number of places on Rock Fork (location 2 ?). At the mouth of this fork an opening shows 19 inches of cannel (fig. 19, section 128), overlain by 35 inches of bituminous coal. On the B. Howard place one opening shows 12 inches of cannel under 3 feet of bituminous coal and another shows 29 inches of bituminous coal between an upper bench of cannel 10 inches thick and a lower bench 14 inches thick. (See fig. 19, sections 126, 127.) On the R. Webb place the same bed (fig. 19, section 125) carries 17 inches of cannel under 39 inches of bituminous coal.[1]

Stone Coal Branch of Right Fork of Beaver Creek.—The Van Lear coal carries from 10 to 17 inches of cannel near the mouth of Stone Coal Branch (location 3). At the mouth 10 inches of cannel underlies 44 inches of bituminous coal. (See fig. 19, section 129.) On the G. Allen land a similar thickness of cannel overlies 34 inches of bituminous coal. (See fig. 19, section 130.) On A. Hayes land, above Stone Coal Branch, 17 inches of cannel underlies 34 inches of bituminous coal.[2] (See fig. 19, section 131.)

Prestonburg.—Owen[3] noted a cannel coal opposite Prestonburg (locations 4, 5) 98 feet above the river. He reports seeing cannel both above and below town, the thickness ranging from 2 feet 8 inches to 3 feet 4 inches.

BREATHITT COUNTY.

Nichols Fork of Frozen Creek.—Cannel coal has been noted at many points along the hillsides near the head of Frozen Creek (location 7). Its thickness has not been determined, but blocks found on the hillside indicate a thickness of at least 2 feet. Two varieties of cannel were noted in this region; one is "hard and very uniform, rather coarse grained structure, showing perfect conchoidal fracture, and abounding in brilliantly polished surfaces or slickensides"; the other "shows a partially laminated structure, irregular fracture, and is of a less homogeneous nature and not nearly so handsome, but it proves on analyses to be one of the best cannel coals of this whole region. It is commonly called the 'curly cannel' owing to its peculiar structure."[4] Analyses (50, 51) are given on page 22.

Jackson.—One of the highest-grade cannel coals of the State has been found within a mile of Jackson on the Joe Little place (location 13). Unfortunately the bed is thin, containing only from 10

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[1] Hoeing, J. B., Kentucky Geol. Survey, 4th ser., vol. 1, pt. 1, pp. 146–147, 1913.
[2] Idem, p. 147.
[3] Owen, D. D., Kentucky Geol. Survey Rept. for 1854 and 1855, p. 208, 1856.
[4] Crandall, A. R., Coals of the Licking Valley region: Kentucky Geol. Survey Bull. 10, p. 58, 1910.

to 16 inches of cannel and underlying only a very few acres (fig. 20, section 132). It has a—

bright, slick, satiny appearance and, on being burned, goes entirely into fine red ash. This is the richest and purest cannel coal that the writer[1] has found in Kentucky, and it is probably unsurpassed anywhere. Sad to relate, a close and careful investigation of the pocket and adjoining hills reveals the existence

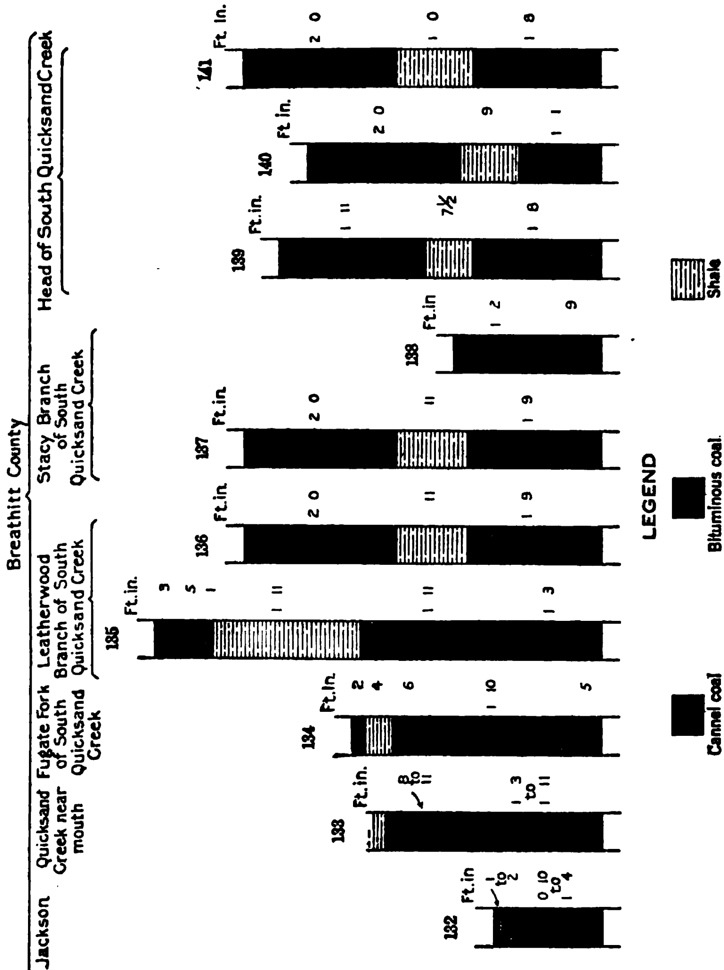

FIGURE 20.—Sections of cannel coal in part of Breathitt County, Ky.

of only about 3 acres of this remarkable coal, another commentary upon the disappointment to which a searcher for this elusive mineral is subjected.

According to an analysis (56, p. 22) by the Consolidated Gas Co. of New York this coal contains 68 per cent of volatile matter and only 28 per cent of fixed carbon and 3.8 per cent of ash.[2] Analyses of Jackson coal (55, 56) are given on page 22.

[1] Hendrie, Charles, Some Kentucky cannels: Kentucky Inspector of Mines Tenth Ann. Rept., p. 143, 1894.

[2] Fohs, F. H., Kentucky Geol. Survey Bull. 18. p. 35, 1912.

Quicksand Creek.—About a mile above the mouth of Quicksand Creek (locations 6 and 9) there is a bed of cannel coal 25 to 26 inches thick, including 8 inches of bituminous coal at the top. From this point the coal extends along the right side of Quicksand Creek for about 3 miles, the cannel part of the bed ranging from 15 to 23 inches and the bituminous from 8 to 11 inches. (See fig. 20, section 133.) The coal, which is a fine cannel (analysis 49, p. 22), was shipped to market many years ago by barges. The cannel is rather restricted in area, but it has been found on Smith Branch of South Quicksand Creek, where the lower layer is a semicannel.[1]

Fulgate Fork.—A pocket of cannel coal (fig. 20, section 134) on Fulgate Fork of South Quicksand Creek (location 10) shows 22 inches of cannel, with bituminous coal both above and below.[2]

Leatherwood Branch.—Both the Wilson Fork and Whitesburg coals carry cannel on Leatherwood Branch of South Quicksand Creek (location 11). The Wilson Fork bed (fig. 20, section 136) shows 21 inches of cannel overlain by 11 inches of shale and 24 inches of bituminous coal and the Whitesburg coal (fig. 20, section 135) contains 15 inches of cannel in one bench and 5 inches associated with bituminous coal in another.[3]

Stacy Branch.—Two beds carry cannel on Stacy Branch (location 14), which enters South Quicksand Creek less than one-fourth of a mile above Leatherwood. The Wilson Fork bed shows 21 inches of cannel in exactly the same section (fig. 20, section 137) as that on Leatherwood Branch. The next coal above shows 14 inches of cannel over 9 inches of bituminous coal (fig. 20, section 138). The Wilson Fork cannel here is of very high grade, as shown by the analyses (57, 58, 58a, p. 22). It is "bright and slick in appearance, ignites readily with a match, and is of excellent quality." The Dictator Cannel Coal Co. is working it at this point.[4] Half a mile farther up Stacy Branch another opening on this bed shows 12½ inches of cannel overlain by 20 inches of bituminous coal.[5]

South Quicksand Creek.—Cannel coal appears abundantly along South Quicksand Creek (location 12) above the mouth of Leatherwood Branch. The following sections show the character of the Wilson Fork coal: Three-fourths of a mile above the mouth of Leatherwood Creek, coal 23 inches, shale 7½ inches, cannel coal (at bottom) 20 inches (fig. 20, section 139); on the opposite side of the creek, in a small branch, coal 24 inches, shale 9 inches, cannel 13

[1] Crandall, A. R., Kentucky Geol. Survey Bull. 10, p. 59, 1910. Fohs, F. H., Kentucky Geol. Survey Bull. 18, p. 37, 1912.
[2] Fohs, F. H., op. cit., p. 24.
[3] Idem, p. 28.
[4] Idem, pp. 30–32.
[5] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., pp. 140–141, 1894.

inches (fig. 20, section 140); on Wilson Fugate Branch, still higher up South Quicksand Creek, coal (mainly splint) 24 inches, shale 12 inches, cannel coal 20 inches (fig. 20, section 141).

The Haddix bed on Wilson Fugate Branch shows 11 inches of cannel on the John Clemmons farm, where the Whitesburg coal con-

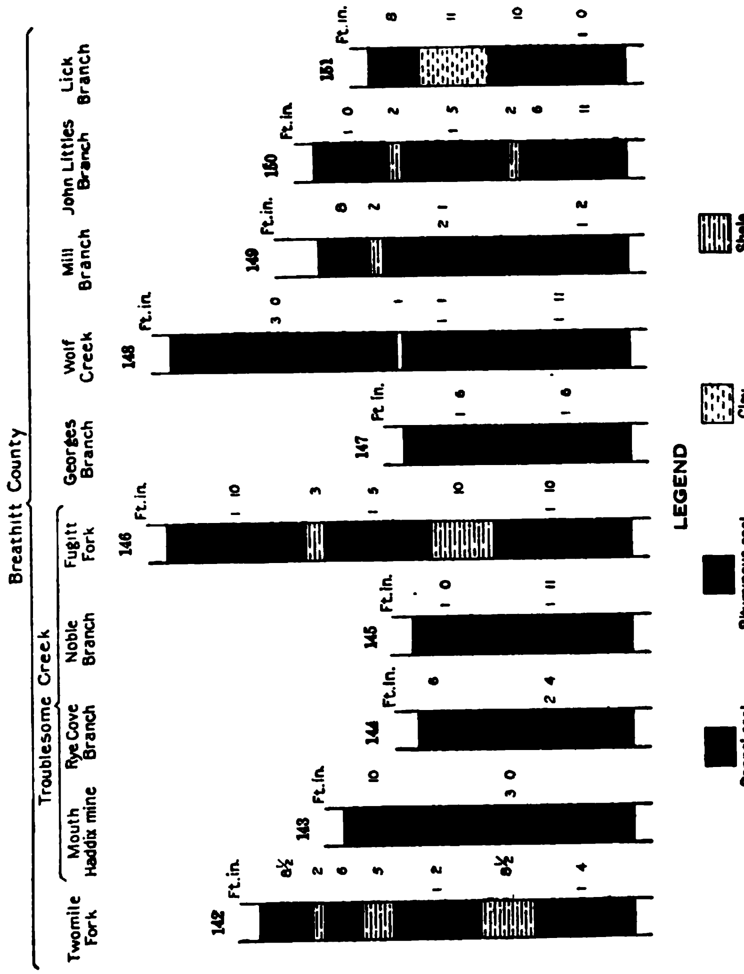

FIGURE 21.—Sections of cannel coal in part of Breathitt County, Ky.

tains two 6-inch benches, and the Wilson Fork bed, 20 feet higher, 1 foot of cannel. This pocket appears to contain, all told, about 300 acres of workable cannel of very high grade.[1]

Twomile Fork.—The Haddix coal has been opened on Twomile Fork (location 16), about 4 miles above the mouth of Leatherwood, at the Alfred Fugate place (fig. 21, section 142), where it shows 14 inches of cannel in a 5-foot bed of coal.[2]

[1] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., p. 142, 1894.
[2] Idem, p. 30.

Troublesome Creek.—Cannel coal was formerly mined at the mouth of Troublesome Creek at the Haddix mine (location 1) and boated down Kentucky River. At the main opening 21 inches of cannel is overlain by 12 inches of bony cannel and 14 inches of bituminous coal.[1] One section (fig. 21, section 143) gave 36 inches of cannel under 10 inches of bituminous coal.[2] Other measurements on this bed in this neighborhood show the variableness of cannel coal. An entry driven 300 yards through the hill to Rye Cove Branch ran out of coal, and another opening on the same bed 100 yards away showed 28 inches of cannel with 6 inches of bituminous above (fig. 21, section 144). A little higher up the branch the coal is 20 inches thick and all bituminous. On the opposite side of Rye Cove the same bed shows 18 inches of bituminous coal and no cannel. Another opening farther down on the same side showed 37 inches of clean, hard, bituminous coal with no cannel; but several hundred yards farther down, an opening shows 35 inches of cannel under 10 inches of bituminous coal. This pocket has been estimated to contain about 50 acres of cannel.[3] Analyses (34–39) are given on page 21.

Noble Branch.—On Noble Branch of Troublesome Creek (location 2) a bed, which may be the Haddix, shows 23 inches of cannel under 12 inches of bituminous coal (fig. 21, section 145). This cannel, which occurs on the Sewell and Little place, is of good quality, as shown by the analysis (40, p. 21).[4]

Fugitt Branch.—On Troublesome Creek, at the mouth of Fugitt Branch, on the Roberts place (location 3), is a thick bed (fig. 21, section 146) containing 22 inches of cannel, which, as shown by the analysis (41, p. 21), approaches semicannel in character. It is described as "a pure-looking coal with but little fibrous coal, and no apparent pyrites. Sample somewhat mixed in character. Some pieces of cannel coal, others splint coal, others apparently shaly."[5]

Georges Branch.—Five miles south of the mouth of Troublesome Creek is the Georges Branch deposit (location 4), one of the most important in the State. The coal regularly and persistently outcrops about 140 feet above drainage for 1½ miles up the creek. This coal had been shipped down the river for many years before a railroad was built into this section. On the Georges Branch Cannel Coal Co.'s land, half a mile from the mouth of the stream, the coal shows 18 inches of cannel, overlain by 8 inches of splint and 12 inches of bituminous coal (fig. 21, section 147). The cannel bed is a "beauti-

[1] Hendrie, Charles, op. cit., p. 132.
[2] Hodge, J. M., Report on the coals of the three forks of the Kentucky River: Kentucky Geol. Survey Bull. 11, p. 26, 1910.
[3] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., p. 132, 1894.
[4] Hodge, J. M., Kentucky Geol. Survey Bull. 11, pp. 28–29, 1910.
[5] Idem, pp. 45–46.

ful, clean, bright cannel coal, tough and elastic." On the Stone Coal Fork of Georges Branch a section showed cannel 18½ inches and coal 17 inches.[1] One mile up Georges Branch there was measured a cannel coal, 17 inches; splint coal, 17 inches; bituminous coal, 3 inches. Apparently Georges Branch runs through the center of the basin, the cannel coal having a nearly regular thickness of 14 to 20 inches. A mile to the south, on the river, the coal is thin and has passed into a slaty cannel; and on the north side of Wolf Creek, the next stream to the south, the coal is a thin semicannel. The basin has been estimated to contain 375 acres of cannel coal. Analyses (43–47) are given on pages 21–22.[2]

Wolf Creek.—On the south side of Wolf Creek (location 5) the cannel is 23 to 27 inches thick (fig. 20, section 148). By its appearance and analysis, however, it here approaches semicannel.[3] (See analysis 48, p. 22.)

Miscellaneous occurrences.—Many deposits showing a foot or less of cannel occur throughout Breathitt County. Sections of two of these deposits between Lost Creek and North Fork and of one west of North Fork are given in figure 21—section 149, on Mill Branch (location 18); section 150, at John Littles Branch (location 19); and section 151, on Lick Branch (location 17). At all these places, as at others, the coal is so resistant that blocks of it accumulate in quantities that give the impression of a greater bed than exists.[4]

JACKSON COUNTY.

Cannel coal has been found at several points in Jackson County. In the valley of Grassy Creek (location 1), in the northeast corner of the county, 14 inches of cannel coal occur on the William Bowles place. Cannel coal is also found on Pond Creek (location 2), not far from the Settle store, Annville (?).[5]

Among the coals analyzed by the Kentucky Geological Survey are two (87, 88, p. 23) from this county, one of which is described as follows: "Cannel coal from Tom Cole's bank, 17 miles southeast of Richmond (location 3), represented to be 21 inches cannel and 21 inches bituminous coal. * * * Rather dull looking cannel coal, splitting with difficulty into layers with not enough fibrous coal to soil the fingers and with no apparent pyrites." The other coal is described as follows: "Cannel coal from T. J. Ballard's place,

[1] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., p. 184, 1894.

[2] Hendrie, Charles, idem. Hodge, J. M., Kentucky Geol. Survey Bull. 11, pp. 70–71, 1910. Crandall, A. R., Kentucky Geol. Survey Bull. 10, p. 65, 1910.

[3] Hendrie, Charles, op. cit., pp. 184–185. Hodge, J. M., op. cit., pp. 72–73.

[4] Hodge, J. M., Preliminary report on the geology of the lower North Fork, Middle and South forks, Kentucky River, p. 90, Kentucky Geol. Survey, 1887.

[5] Miller, A. M., Coals of the lower measures along the western border of the eastern coal field: Kentucky Geol. Survey Bull. 12, pp. 75–76, 1910.

branch of Horselick, 26 miles from Richmond (location 4). * * * Specimen from the outcrop. * * * Resembles the preceding, has a bird's-eye structure in parts."[1]

LETCHER COUNTY.

Mill Branch of Rockhouse Creek.—On the J. Q. Bentley place, at the mouth of Mill Branch (location 6), and again at the mouth of

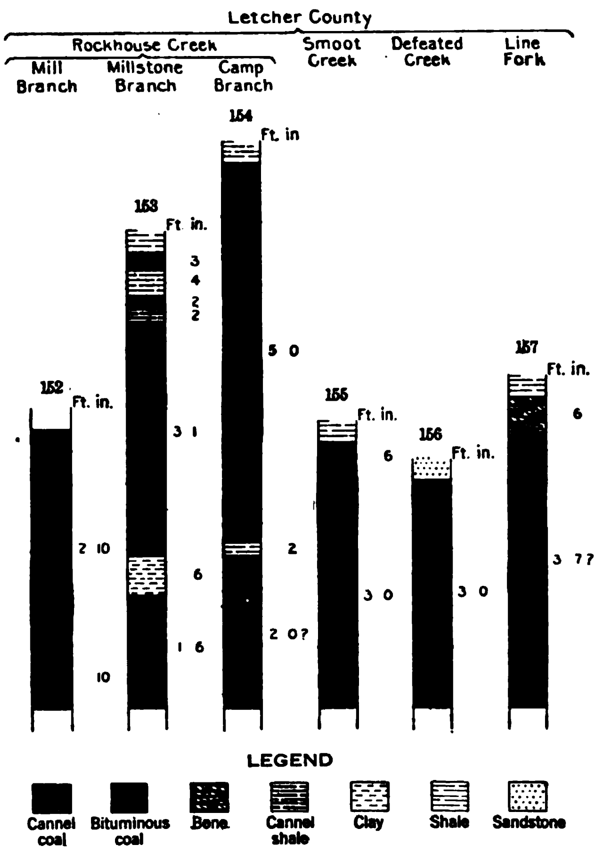

FIGURE 21.—Sections of cannel coal in Letcher County, Ky.

Potters Fork, the Elkhorn coal carries 10 inches of semicannel coal under 34 inches of bituminous coal[2] (fig. 22, section 152, and analysis 106, p. 24).

Millstone Branch of Rockhouse Creek.—The "fire-clay" or Dean coal on Millstone Branch (location 3) carries at its base 18 inches

[1] Peter, Robert, Chemical analyses: Kentucky Geol. Survey Rept. A, pt. 1, pp. 272–273, 1884.

[2] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 145, 1910.

of cannel without partings, described as a fine-looking coal[1] (fig. 22, section 153, analysis 104, p. 24).

Camp Branch of Rockhouse Creek.—On Camp Branch, on the J. N. Collins place (location 4), the cannel at the base of the Dean coal is 2 feet thick[2] (fig. 22).

Smoot Creek.—Near the mouth of Smoot Creek (location 5) the Whitesburg is a cannel coal 18 inches to 3 feet thick (fig. 22, section 155).[3]

Defeated Creek.—The Dean coal is mostly cannel on Defeated Creek (locations 1 and 2). Where it goes under the creek it measures 3 feet of solid cannel under a massive sandstone (fig. 22, section 156). On the Ira Hall place, 2 miles above the mouth, it is 25 inches thick, including 3 inches of shale 7 inches from the top.[4] (See analysis 105, p. 24.)

On Line Fork, 2 miles above the mouth of Defeated Creek, on the Joseph Cornett place (location 1), the bed shows 43 inches of high-ash cannel (analysis 103, p. 24), grading into bituminous shale at the top (fig. 22, section 157). It is described as "a bright, rather pure looking cannel."[5]

LESLIE COUNTY.

Cutshin Creek.—Six miles above Paul Creek, on Coon Creek (location 1), the Dean or "fire-clay" coal carries 32 inches of cannel under 6 inches of bituminous coal (fig. 23, section 158). Hodge[6] says this bed "though rare as cannel on the Middle Fork (of Kentucky River) is quite common as such on the North Fork, and the rider has cannel to the southwest on Greasy Creek and elsewhere."

Laurel Fork.—Three miles up Laurel Fork and one-eighth of a mile to the left up Wolfpen Branch and 50 feet above it, on the Arch Cornett place (location 3), is 23 inches of cannel, with 28 inches of bituminous above and 16 inches of bituminous below (fig. 23, section 159). One analysis given (100, p. 24) is of the cannel bed; another (101) is of the cannel bed and the 6-inch bed of bituminous coal immediately below.[7]

Beech Fork.—On Oldhouse Branch of Beech Fork of Middle Fork of Kentucky River (location 2), the rider of the "fire-clay" coal is a cannel 38 inches thick (fig. 23, section 160, and analysis 102, p. 24).[8]

[1] Hodge, J. M., Kentucky Geol. Survey Bull. 11, p. 135, 1910.
[2] Idem, p. 137.
[3] Idem, p. 150.
[4] Idem, p. 126.
[5] Idem, p. 127.
[6] Idem, p. 195.
[7] Idem, p. 196.
[8] Idem, p. 222.

PERRY COUNTY.

Lots Creek.—On Lots Creek, near Grigsby (location 1), 21 inches of cannel underlies 23 inches of bituminous coal (fig. 23, section 162) in what seems to be a fair-sized pocket. An analysis (131) is given on page 25.

Lost Creek.—On Lost Creek (location 2) two coals (Nos. 4 and 5) carry cannels. The cannel with coal No. 4 is generally thin; that with No. 5 is 10 to 22 inches thick, with a considerable thick-

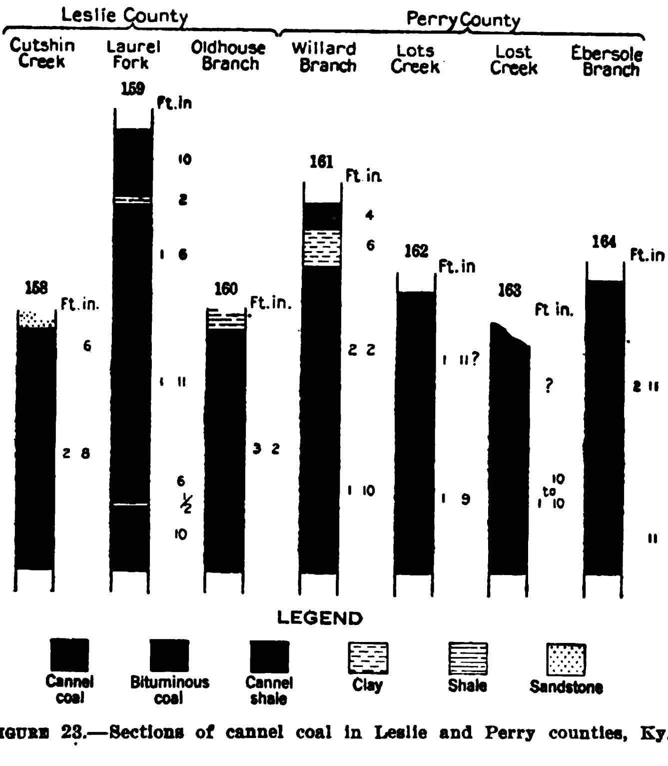

FIGURE 23.—Sections of cannel coal in Leslie and Perry counties, Ky.

ness of bituminous coal above (fig. 23, section 163), but the cannel is not of first-class quality.[1]

Ebersole Branch.—On Ebersole Branch of North Fork of Kentucky River (location 3), 11 inches of cannel underlies 35 inches of bituminous coal (fig. 23, section 164).[2]

Squabble Branch.—The same bed shows some cannel on Squabble Branch of Middle Fork of Kentucky River (location 4). Blocks of cannel at an old opening a mile from the mouth of the creek indicate the presence of some good cannel coal.[2]

[1] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., p. 143, 1894.

[2] Hodge, J. M., Preliminary report on the geology of the lower North Fork, Middle and South forks, Kentucky River, p. 83, Kentucky Geol. Survey, 1887.

North Fork of Kentucky River.—Eight inches of cannel coal occur on the Elijah Davidson place, 3 miles above the mouth of Grapevine Creek. On the Samuel Whittaker place (locality 5), on Willard Branch, the same bed contains 22 inches of cannel. (See fig. 23, section 161.)

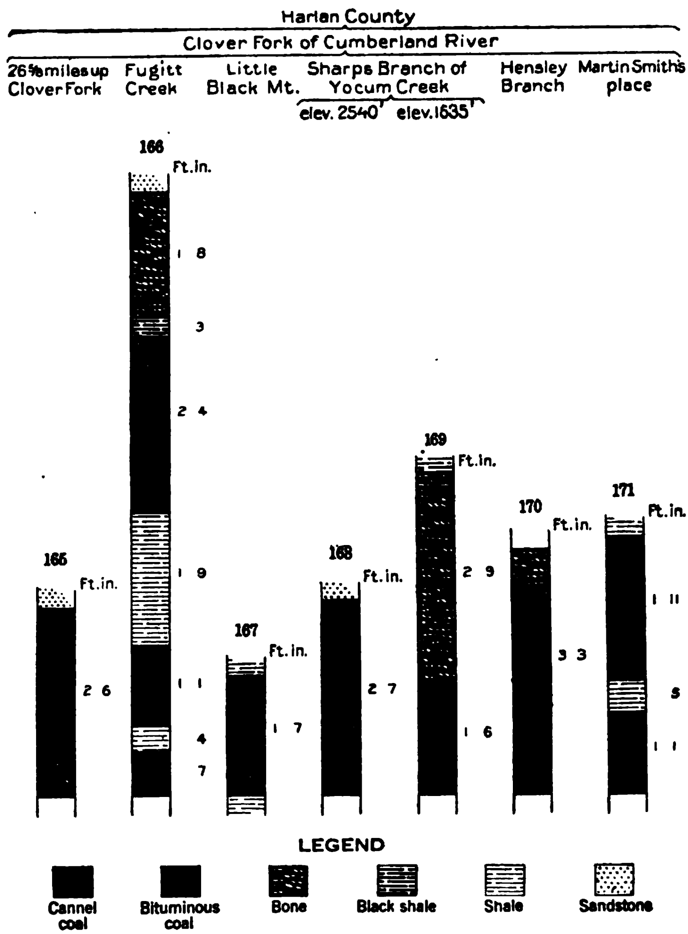

FIGURE 24.—Sections of cannel coal on Clover Fork of Cumberland River, Harlan County, Ky.

Middle Fork.—On Middle Fork of Kentucky River (location 6) a mile below the mouth of Rush Creek 10 inches of cannel coal inclosed in 24 inches of bituminous coal is found.[1] An analysis (132) is given on page 25.

HARLAN COUNTY.

Jack Bailey Branch.—On the Wright Short place, 26⅝ miles above the mouth of Clover Fork, at the mouth of Jack Bailey Branch (loca-

[1] Hodge, J. M., op. cit., p. 88.

tion 6), is found 30 inches of cannel (fig. 24, section 165) in the Kelioka coal (Keokee of State reports). The basin seems to be very small, for 150 yards away an opening shows only 11 inches of cannel and 24 inches of bituminous coal.[1]

Fugitt Creek.—About one-fourth of a mile up Fugitt Creek (location 5), about 750 feet above sea level, a bed (fig. 24, section 166) contains 28 inches of cannel of doubtful quality and 20 inches of cannel-like shale associated with some bituminous coal and much shale.[2]

Little Black Mountain.—On Little Black Mountain, below the mouth of Fugitt (location 4), the Kelioka coal (fig. 24, section 167) is only 19 inches thick but is all cannel.[3]

Sharps Branch.—On Sharps Branch, 3¾ miles above the mouth of Yokum Creek, in Horse Hollow of the Left Fork (location 3), 31 inches of cannel coal lies about 2,540 feet above sea level. Farther down the same branch, at about 1,635 feet, 15 inches of cannel shale is underlain by 25 inches of bituminous coal. At another opening near by the shaly cannel is 33 inches in thickness. The upper bed on Bailey Creek is also partly cannel.[4] (See fig. 24, sections 168, 169, and analysis 82, p. 23.)

Hensley Branch.—The Kelioka bed is a cannel coal on Hensley Branch (location 1) 2 miles above the mouth of Clover Fork. It is here 39 inches thick (fig. 24, section 170), the upper part, however, grading over into a cannel shale.[5]

Clover Fork.—On the Martin Smith place, 1½ miles above the mouth of Hensley Branch (location 2), the Kelioka bed (fig. 24, section 171) carries 23 inches of cannel separated by 5 inches of shale from 13 inches of bituminous coal.[6]

Lick Branch of Poor Fork.—On Lick Branch (location 7) the Kelioka bed shows 28 inches of cannel of good appearance, light weight, and good fracture, overlain by 33 inches of cannel shale (fig. 25, section 172). It is said that a piece of this cannel, about 6 to 8 inches cube, when broken open was found to contain in the middle a lump of pure splint coal 1 by 2 by 3 inches.[7]

Johns Branch of Catron Creek.—On Johns Branch, on the Myra Osburn place (location 15), 40 feet above the Harlan coal 30 inches of cannel is overlain by 22 inches of bituminous coal. Other measurements on Johns Branch have shown 2 feet 9 inches of cannel overlain

[1] Hodge, J. M., The upper Cumberland coal field: Kentucky Geol. Survey Bull. 13, p. 108, 1912.
[2] Idem, p. 82.
[3] Idem, p. 80.
[4] Idem, pp. 51–52.
[5] Idem, p. 38.
[6] Idem, p. 39.
[7] Idem, p. 152.

by 21 inches of bituminous coal. (See fig. 25, section 173, and analysis 83, p. 23.)

An analysis (84, p. 23) is of a sample described as taken "8 miles from Mount Pleasant (Harlan) at the head of Catron Creek of Martin Fork. Sample from 22-inch seam in bed containing three seams, two of stone coal, severally 18 inches and 6 inches thick, sep-

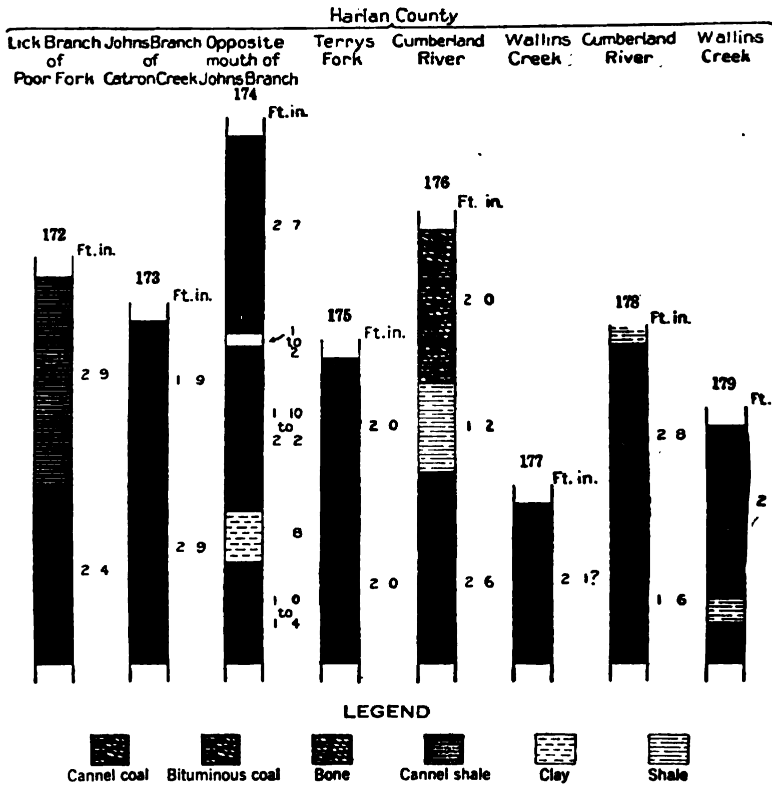

FIGURE 25.—Sections of cannel coal in Harlan County, Ky.

arated by 2 inches of shale parting; 120 feet above drainage; a dull gray-black cannel coal, irregularly laminated."[1]

Catron Creek.—Opposite the mouth of Johns Branch on the Washington Hensley place (location 14) is a good showing of cannel coal. The bed comprises, from the top down, 2 feet to 2 feet 7 inches of bituminous coal, 1 to 2 inches of clay, 22 to 26 inches of cannel (the lower part of which is a good cannel with conchoidal fracture), 8 inches of clay, and 12 to 16 inches of cannel. (See fig. 25, section 174.) Two analyses (83, 86, p. 23), which include both benches of

[1] Ashley, G. H., and Glenn, L. C., U. S. Geol. Survey Prof. Paper 49, pp. 200–201, 1906.

cannels, show that these coals, though low in ash, are also low in volatile matter.[1]

Martin Fork near Hurst.—Cannel coal is reported to lie 50 feet above the Harlan coal at the Stephen Place mine on Martin Fork, near Hurst (location 13). As this is on the opposite side of the ridge from the cannel coal at the same horizon on Johns Branch, it is possible that there is a fair-sized area of cannel coal in this district.

Wallins Creek.—What has been called the Terrys Fork coal carries cannel over a good-sized area near the mouth of Wallins Creek. It is typically exposed on Terrys Fork near the mouth (location 8), where it shows a thickness of 24 inches of cannel over 24 inches of bituminous coal, on the Adrian Howard place (fig. 25, section 175). Over the ridge to the northeast on Cumberland River, opposite the mouth of Watts Creek (location 16), the same bed shows 24 inches of shaly cannel over 30 inches of bituminous coal (fig. 24, section 176). Around the divide between Terrys Fork and Wallins Creek on the Wallins Creek side, on Mrs. L. Howard's place (location 9), what is apparently the same bed shows 30 inches of cannel coal overlying 14 inches of shale and 24 inches of bituminous coal. A little farther up Wallins Creek this coal has been opened up, or faced up, at several points (location 17), showing about 25 inches of cannel coal (fig. 25, section 177). Below the mouth of Wallins Creek, on the trail passing over the ridge to Jesse Creek (location 10), the same bed contains 32 inches of cannel above 18 inches of bituminous coal (fig. 25, section 178). On the D. F. Noe place on Wallins Creek (location 12) 27 inches of cannel is reported to overlie 3½ inches of shale and 6½ inches of bituminous coal (fig. 25, section 179). This same coal shows 10 inches of cannel on the Banner Fork of Wallins Creek and 4 inches of cannel on Camp Branch.[2]

BELL COUNTY.

Pineville.—Cannel coal has been mined on Stewarts Branch near Pineville (locations 1 and 3) by the Breckenridge & Pineville Syndicate (Ltd.), later the Wallsend Coal & Coke Co., and at present The Federal Coal Co. The cannel bed is what is locally called the McGuire bed, overlying the Dean coal. An analysis (31) is given on page 21. The occurrence of the coal has been described by Crandall as follows:[3]

The McGuire cannel seam, or the Upper Dean coal, at the 762-foot level on Stewart Branch is continuous over a large part of this region, rising to the

[1] Ashley, G. H., and Glenn, L. C., op. cit., pp. 196–198.

[2] Idem, p. 158.

[3] Crandall, A. R., and Sullivan, G. M., Kentucky Geol. Survey Bull. 14, pp. 106–107, 1912.

crest of the hills near the head of the Pogue Branch. The cannel portion of the bed is not so constant a feature either in thickness or in quality as to give value to this coal seam. On the right fork of Stewart Branch, as faced up for examination but not driven to solid coal, the whole thickness was 59 inches, of which the bottom bench of cannel coal was 17 inches. A greater thickness has been reported near the head of Millers Branch. But at the head of the left prong of Stewart Branch and at a point to the westward Mr. Thurston measured 38 inches of common coal and 18 inches of cannel, and 39 inches and 13, respectively. This bed makes a horizon which has recurring local areas of cannel coal in connection with ordinary soft coal; it extends over a large field in greater or less thickness, with here and there pockets of cannel coal added to its bed section or taking the place of some of its layers, as the case may be; but it has only at wide intervals bodies of cannel which separately may be made the basis of a mining industry.

Where the coal was mined the cannel bench showed (fig. 26, section 180) a thickness of 18 inches overlain by 34 inches and more of bituminous coal.[1] In the mine inspector's report for 1899[2] it is stated that "there is an almost inexhaustible supply of the Pineville cannel"; and again that "the No. 2 mine is in a vein 50 inches thick, of which 12 inches at the top is cannel." In describing this property the chief engineer of the company says: "This seam is about 4 feet thick and carries a cannel seam from 8 to 24 inches thick" (fig. 26, section 181).[3]

Chenoa.—On Bear Creek branch of Clear Creek (location 2) is a body of cannel coal that was mined extensively from 1893 to 1899. The cannel here as usual proved to be in a basin in which the width of workable coal was only 600 feet. This was followed down the dip for about 4,000 feet at constantly increasing cost until 1899, when the burning of the tipple led to the abandonment of the mine. The dip of this basin is steep, being about 8° for the first 400 or 500 feet and 5° for the next 400 or 500, beyond which it gradually decreases to 2° or less. When operations ceased plans were on foot for making a new opening by a slope in order to reach the coal near the present face. This coal shows a total section of over 7 feet in the center of the basin, thinning out to the edges. The upper part is bituminous and the lower part cannel. One section, reported by A. R. Crandall,[4] gave 34 inches of bituminous coal at the top separated by 1 inch of charcoal from 52 inches of cannel coal at the bottom. The section measured near the ventilating furnace, however, showed the bed much broken up, the cannel appearing in two benches, the upper of 7 inches and the lower of 14 inches, the whole bed having a thickness of 97 inches. As a rule, however, there is here a single block of bituminous coal above a shale parting which

[1] Norwood, C. J., Kentucky Inspector of Mines Tenth Ann. Rept., p. 119, 1894.
[2] Stone, G. W., Kentucky Inspector of Mines Sixteenth Ann. Rept., pp 112, 140, 1900.
[3] Norwood, C. J., Kentucky Inspector of Mines Ann. Repts. for 1905, 1906, p. 169, [1907?].
[4] Ashley, G. H., and Glenn, L. C., op. cit., p. 94.

may resemble cannel at the top or bottom. The thickness of the cannel-coal bench ranges from about 55 inches in the center of the basin to 30 inches at the sides where mining stopped. It may be assumed that this basin, or channel, extends eastward or southeastward through the ridge. (See fig. 26, sections 182, 183, and analysis 32, p. 21.)[1]

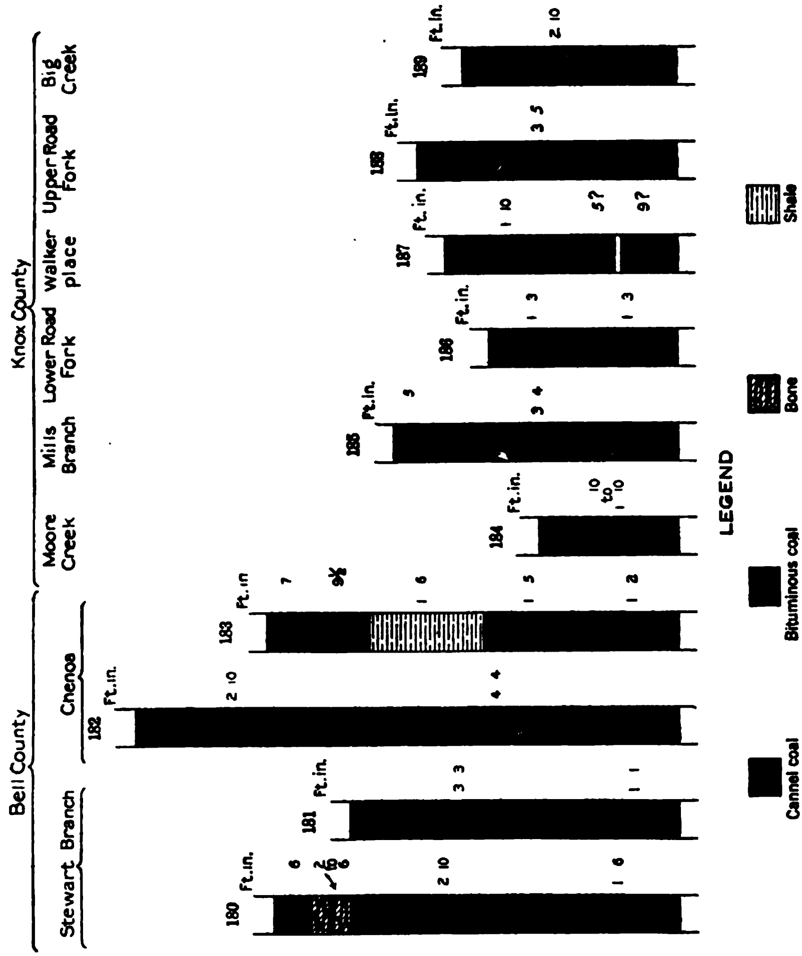

FIGURE 26.—Sections of cannel coal in Bell and Knox counties, Ky.

KNOX COUNTY.

Cannel coal in Knox County, so far as described, appears to be confined to the valley of Stinking Creek and to one exposure on Bull Creek. All of the following areas, except the last, are on tributaries of Stinking Creek.

Moore Creek.—On the left fork of Moore Creek (location 6) 10 to 22 inches of cannel (fig. 26, section 184) has been found in a bed

[1] Ashley, G. H., and Glenn, L. C., U. S. Geol. Survey Prof. Paper 49, pp. 94–95, 1906.

thought to be above the Dean and probably at the horizon of the McGuire coal, which is cannel bearing in Bell County.[1]

Mills Branch.—At the Anderson Mills entry on Mills Branch, 280 feet above the creek (location 4), the cannel bed has a thickness of 45 inches (fig. 26, section 185), including 5 inches at the top, which is partly splint. The coal appears to be limited to a pocket in the ridge between Mills Branch and Dickey Branch to the north.[2]

Lower Road Fork.—The McGuire bed is cannel bearing at the Williamson place at the mouth of Lower Road Fork (locations 2 and 7). The cannel is 15 inches thick overlain by 15 inches of bituminous coal (fig. 26, section 186). At the Walker farm, 1½ miles up the creek, the cannel carries a 1-inch clay parting 5 inches from the top and a bituminous bench 22 inches thick (fig. 26, section 187). The coal is here about 400 feet above the creek. This bed has been widely recognized toward the heads of the forks of the main Stinking Creek, though the cannel part of the bed is commonly thin or absent.

Upper Road Fork.—Toward the head of Upper Road Fork (location 3) the McGuire coal attains a workable thickness. Thus at David Price's place, 7 miles above the mouth of the fork, the cannel coal is 41 inches thick (fig. 26, section 188), but from here it thins in every direction. The workable portion is limited to the ridge between the main fork and Spring Branch. An analysis (97) is given on page 24.[2]

Middle Fork.—Near the mouth of Middle Fork, about 650 feet above the creek (location 5), on the J. M. Bingham place 13 inches of cannel coal overlies 24 inches of bituminous coal and underlies 3 inches of bituminous coal. On the Big Creek side of this same ridge and a mile away this bed shows 12 inches of cannel over 24 inches of bituminous coal at the Acy Messers opening. It is readily traced along Big Branch by the outcropping cannel.[3] On Brown Branch of Middle Fork a few openings have been made to this coal, showing about the same thickness as at the Walker opening (location 5) on the opposite side of the ridge. On the Jeff Hammond Fork of Middle Fork the cannel coal is 6 to 8 inches thick. On Tom and Wash branches of Salt Gum Branch of Middle Fork the cannel is from 9 to 11 inches thick and is overlain by 5 inches of cannel shale.

Big Creek (main branch?).—On Broughton Branch at the B. D. Allen mine (location 1) the cannel bed reaches a maximum of 34 inches (fig. 26, section 189), but decreases in thickness in a short distance. Other cuts in this neighborhood failed to develop pockets of promise. On the Buckeye and Acorn branches of Big Creek, which head against the head of Salt Gum Fork of Middle Fork, the

[1] Crandall, A. R., and Sullivan, G. M., Kentucky Geol. Survey Bull. 14, p. 127, 1912.
[2] Idem, p. 125.
[3] Idem, p. 128.

cannel bed carries 13 inches of cannel. It is 9 inches thick near the Isaac Taylor place, 4 miles from the head in a bed 14½ inches thick, and 8 inches thick 3½ miles below the head.[1]

Bull Creek.—On the T. Jones place, 2 miles up Bull Creek of Colon Fork of Goose Creek 15 inches of cannel is reported.[2] Near the mouth of Bull Creek (location 8), on the Harpers land, the cannel is 26 inches thick but is very shaly.

CLAY COUNTY.

The bed of cannel coal found on Middle Fork of Stinking Creek in Knox County has been opened also on the headwaters of Kentucky River (location 1) in Clay County.[3]

A table of analyses published by Hodge[4] includes two of cannel coal from Clay County, one of which (analysis 69, p. 22) is described as from J. T. Smith's place on Tom's Branch (cannel 5 inches), and the other (analysis 70, p. 22) from the J. M. Jones place (location 2), Beech Creek, Clay County (cannel 15 inches).

LAUREL COUNTY.

Cannel coal 4 feet 2 inches thick is reported to have been opened on Cane Creek about 2½ miles north of the Chris Hale place in Laurel County. At another opening on Indian Camp Branch of Craigs Creek apparently the same bed, coming immediately under the cap rock of the plateau in this area, has been opened and shows 36 inches of cannel overlying 8 inches of sandy shale and coal and 6 inches of bituminous coal.

WHITLEY COUNTY.

Character of the coal.—Part of Whitley County is underlain by a coal having a peculiar pitted fracture, to which the name bird's-eye is given. The bed, which is now thought to be the same as the Jellicoe, ranges from a rich pure cannel to a semicannel or splint coal and to a black coal. The bird's-eye fracture persists through the several changes, though it does not everywhere persist through the whole thickness of the bed. None of the analyses at hand indicates that any of this coal is a high-volatile cannel, though such cannel may exist in the region. The peculiar fracture is most striking at right angles to the bedding.[5] As shown on the map (Pl. VII, p. 82)

[1] Crandall, A. R., and Sullivan, G. M., Kentucky Geol. Survey Bull. 14, p. 127, 1912.

[2] Hodge, J. M., Preliminary report on the geology of the lower North Fork, Middle and South forks, Kentucky River, p. 74, Kentucky Geol. Survey, 1887.

[3] Crandall, A. R., and Sullivan, G. M., op. cit., p. 128.

[4] Hodge, J. M., op. cit. p. 96.

[5] Crandall, A. R., Report on the geology of Whitley County, etc., plate opposite p. 87, Kentucky Geol. Survey, 1889 [date of map].

the cannel and semicannel condition of this bed centers mainly in the Patterson Creek region but is found also on Big and Little Caney and Mud and Polar creeks. Though not a rich coal for the manufacture of oil, it is free burning and is adequate for many of the uses of cannel.

Patterson Creek.—Near the head of Patterson Creek (fig. 27, section 190) 52 inches of block coal shows at the Polly mine (locations 1, 3, 5, and 6), of which 31 at the base is bird's-eye. On Bennett Fork of Patterson Creek (location 3, section 193) the bed is from 48 to 50 inches thick and is a semicannel. On the Lawson tract the bed shows 11 inches of bird's-eye at the base, then 13 inches of

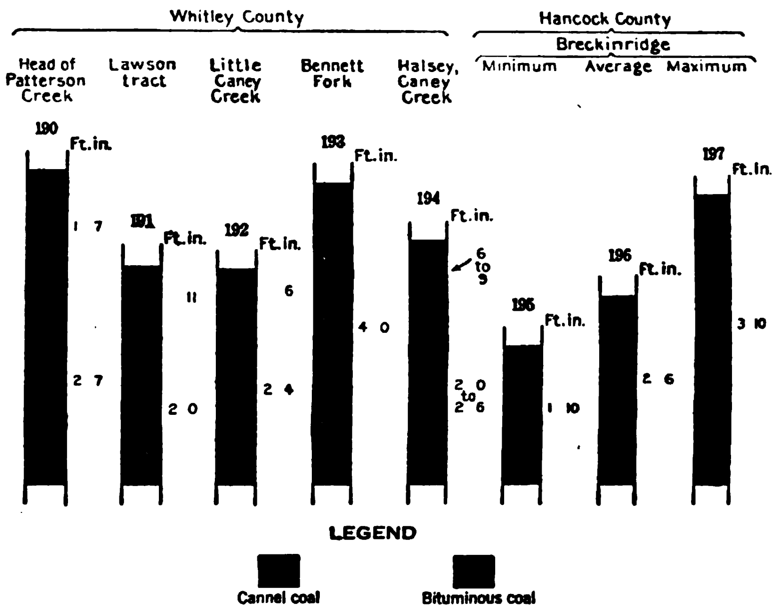

FIGURE 27.—Sections of cannel coal in Whitley and Hancock counties, Ky.

cannel, then 11 inches of bituminous coal[1] (fig. 27, section 191, and analyses 134, 136, p. 25). This bed is a cannel coal on Mud Creek also (locality 4).

Little Caney.—At the head of Little Caney (location 2) the bed carries 28 inches of cannel and 6 inches of bituminous coal.[2] (See fig. 27, section 192, and analysis 137, p. 25.)

Halsey.—At Halsey on Caney Creek (location 7) the Jellicoe and Birdseye Coal Co had, in 1893, made a number of openings on the bird's-eye coal. At the Halsey mine the coal (analysis 138, p. 25) con-

[1] Hendrie, Charles, Kentucky Inspector of Mines Tenth Ann. Rept., p. 147, 1894.
[2] Crandall, A. R., op. cit., p. 38. Miller, A. M., Kentucky Geol. Survey Bull. 12, p. 69, 1910.

tained (fig. 27, section 194) 2 feet or a little more of bird's-eye and semicannel, and 6 to 9 inches of bituminous coal.[1]

HANCOCK COUNTY.

The famous Breckinridge cannel coal, probably the best known of the Kentucky cannels and the oftenest mentioned of American cannels, lies in Hancock County just over the boundary from Breckinridge County.

The extent of the cannel coal is not known. Mining was carried on in a ridge between Tarr Fork and Panther Creek, the mines being on the Tarr Fork side. It has been generally assumed that the cannel-coal field is exhausted. Norwood,[2] after examining the area in 1875, concluded that a large body of cannel coal, possibly 4,000 acres, still remained. Mining was resumed and it is possible that when it finally ceased all the coal at that time minable had been removed. The cannel bed lies at the base of the coal-bearing rocks and was from 22 to 38 inches thick, locally reaching 46 inches. The average is given as about 2½ feet or a little over. (See fig. 27, sections 195–197, and analyses 75–80, p. 23.)

Miscellaneous localities.—In other parts of the western field of Kentucky coals Nos. 1, 5, and 11 locally carry workable thicknesses of cannel. Usually these are mined along with the bituminous coal, which they accompany, no attempt being made to find separate markets for the cannel portion of the bed. Near Dekoven coal No. 11 carries 14 to 15 inches of cannel overlying a small amount of bituminous coal. Cannel has been noted associated with this bed in Muhlenberg and Union counties, though it is usually of poor quality. Coal No. 5 also contains cannel at Dekoven, where a 25-inch bench lies between two 6-inch benches of bituminous.

TENNESSEE.

In Tennessee cannel coal is mined only south of Jellico, about 2 miles from Newcomb, in Campbell County, where for some years it has been mined by the Jellico Cannel Coal Co. The bed has an average thickness of 30 to 36 inches and lies about 1,800 feet above sea level. Benches of cannel coal of small lateral extent occur at Bon Air and Whitwell and at a few other places in the State.

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[1] Norwood, C. J., Kentucky Inspector of Mines Tenth Ann. Rept., pp. 128, 177, 1894.

[2] Norwood, C. J., Report of a reconnaissance of a part of the Breckinridge cannel-coal district: Kentucky Geol. Survey Repts. Progress, vol. 4, new ser., p. 352, 1878; Western coal field, p. 206, Kentucky Geol. Survey, 1884.

ALABAMA.

In the Cahaba coal field of Alabama, west of Montevallo and northwest of Briarfield, an area of overturned rocks includes several coal beds.[1] One of these, "the cannel seam," occurs on Little Mayberry Creek and is described by Squire as 3 to 3½ feet thick and partly bony. Squire adds that the bed is overturned and dips 56°. In the same chapter Squire gives an analysis of the "B" bed, showing 56.1 per cent of volatile matter, 37.4 per cent of fixed carbon, and 3.1 per cent of ash, but does not make clear whether this is the "cannel seam." Its resemblance to a cannel-coal analysis and the contrast with other analyses of coals in that area suggest that it may be.

IOWA.

Cannel coal is found in Iowa only near Fort Dodge and in a few other localities. The bed in the vicinity of Fort Dodge, which occurs near the base of the coal-bearing rocks, extends over a moderately large area along the river and appears to be rather more regular than the bituminous beds just above it, some of which are very pockety, varying several feet in thickness in less than 100 yards. North of Fort Dodge the cannel seam is 20 to 30 inches thick. Three mines have recently operated near Kalo. At the Johnson mine the cannel occurs as a 16-inch bed separated by 3 inches of shale over an underlying bench of bituminous coal 22 inches thick; at the Irvine mine at Kalo the coal is 28 inches to 3 feet thick; at the Craig & Dawson mine the cannel is about 3½ feet thick.[2] The coal is overlain by shale and underlain by shale or clay at all of these places. On Holaday Creek, near Coalville, the seam consists of 4 to 9 inches of cannel above 1 to 3 feet of bituminous coal.[3]

At the Tann mine, in Guthrie County, in the NE. ¼ SE. ¼ sec. 22, T. 79 N., R. 30 W.,[4] there is 22 inches of cannel which is just on the border line between cannel and bituminous, showing about equal percentages of volatile matter and fixed carbon or a fuel ratio very close to 1. The ash ranges from 15 to 36 per cent in the analyses at hand and the sulphur from 7 to 11 per cent. The high sulphur content would be sufficient to prevent the use of this coal for some purposes.

MISSOURI.

OCCURRENCE OF THE COAL.

In a broad area southeast of the main coal field of Missouri there are pockets of "Coal Measure" rocks, many of which contain beds

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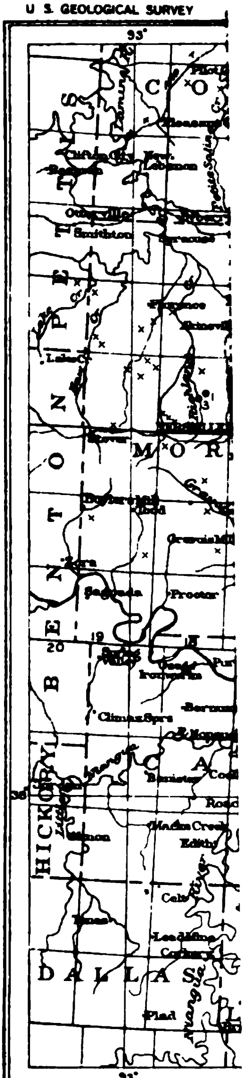
[1] Squire, Joseph, Report on the Cahaba coal field, pp. 97–100, Alabama Geol. Survey, 1890.

[2] Keyes, C. R., Coal deposits of Iowa: Iowa Geol. Survey, vol. 2, pp. 204, 205, 1894.

[3] Idem, pp. 40, 42, 43.

[4] Idem, p. 247.

U S. GEOLOGICAL SURVEY



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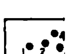

Deposits referr
(Separate series of numl

of cannel coal. (See Pl. VIII.) Most of these pockets appear to be in old sink holes, dissolved out of the limestones, though some are in narrow valleys. Such pockets occur in 35 counties. The coal in many places is remarkably thick, some deposits measuring more than 50 feet and one shaft having penetrated nearly 90 feet. Though these coals have not been analyzed, they are described as commonly high in ash and high in volatile matter. Many of these pockets, like the cannel basins in Kentucky and elsewhere, have been the basis for unprofitable investment and probably more money has been spent on them than has been made out of them. Most of the basins to be described are circular or oval and not more than a few hundred feet in diameter. An aggregate of 500,000 tons in a single pocket is exceptionally large, most of them being very much smaller. In some places seams and bands of lead or zinc ore add to the value of the pocket, and in others small deposits of flint clay and plastic clay occur with the coal and may be mined with it at a profit. Cannel coal occurs in such pockets in Benton, Boone, Callaway, Cedar, Cole, Cooper, Clark, Crawford, Camden, Dade, Douglas, Dent, Jasper, Lewis, Lincoln, Marion, Miller, Moniteau, Montgomery, Morgan, Pike, St. Charles, St. Clair, St. Louis, Saline, Warren, and other counties. Recent mining appears to have been confined to Moniteau, Cole, Monroe, and Morgan counties. Further description will be confined to such deposits as have been worked in recent years or are now being worked.

CALLAWAY COUNTY.

Many pockets, some of remarkable thickness, occur in the southern and eastern parts of Callaway County, but not one of them contains more than a small amount of coal. One of them, near Hams Prairie, in the NE. ¼ sec. 16, T. 46 N., R. 9 W., is worked by W. C. Weeks. The coal is 5 to 12 feet thick, the lower part cannel and the upper part bituminous. Hinds[1] says:

> Callaway County has long been noted for its pockets of thick coal, and much money has been wasted by those who have attempted to mine them on a large scale. Although many are remarkably thick, containing as much as 80 feet of coal, most of them are very small in lateral dimensions and do not contain more than sufficient coal for purely local use. These pockets occur in all parts of the county, but are exposed only outside the area covered by the main body of the Pennsylvanian ("Coal Measures"). They are especially well known in the rough country near the Missouri River, where many were mined during early days to supply fuel for the boats then so numerous on the river. Many old workings may be observed near Hibernia and Mokane, and exaggerated statements as to the amounts of coal in those districts are still current.

[1] Hinds, Henry, The coal deposits of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 11, p. 114 [1912].

COLE COUNTY.

Many coal pockets have been found in Cole County, especially near Centertown and Elston, and some mining has been done there. Probably, however, more money has been spent in prospecting for coal in this county than has been made by mining. Many of the pockets were described by Broadhead,[1] chiefly those north of Centertown. The most recent mining at this point on cannel coal is said to have been on the Leonard farm, 2 miles north of Centertown (location 1 [2]), where a pocket 200 feet in diameter, carrying 14 feet of cannel above 4 feet of bituminous coal, was worked for three years from a 30-foot shaft. On the Bryant place 2 miles northeast of Centertown (location 2) are 20 to 30 feet of cannel, which were formerly stripped.[3] Cannel coal was being mined in 1911, if not at present, at the S. & A. Bandelier mine, 1½ miles due south of Elston (location 3). The coal is in a pocket 250 feet wide from east to west and somewhat longer from north to south.[3]

Section at the S. & A. Bandelier coal pocket, Cole County, Mo.

	Feet.
Clay	20
Bone	4
Coal, bituminous	6
Shale, "slaty"	10
Cannel coal, bottom not reached	59

The coal lies nearly flat in the center of the deposit, but the bedding turns up to 80° at the edges as though held back in the settling of the material of the pocket at some time subsequent to its laying down. Between the coal and rocks in the pocket and the outside walls a layer of clay, like that commonly found in fault planes, made the pocket a natural reservoir, so that when the mine was opened 6,000 barrels of water had to be pumped out, after which no further difficulty of that kind was encountered. The cannel is very clean, with a little pyrite and zinc blende near the outer edge of the pocket. It splits easily with the bedding, but has no other regular fracture. Eighty-six feet of coal under 12 feet of soil is reported, as shown by a drilling on the Stehlein farm not far from this mine.

Near Hickory Hill (location 4) the Dustless Coal Co. opened a mine after constructing a 7-mile spur from Henley. The prospect shaft is reported to have cut 82 feet 9 inches of cannel coal, bearing galena and zinc blende. When visited by Hinds[4] in 1911, 8 feet of cannel were exposed in a pit at the shaft mouth.

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[1] Broadhead, G. C., Cole County: Missouri Geol. Survey Rept. for 1873–74, pp. 322–338, 1874.

[2] Locations in Missouri are numbered by counties. (See Pl. IX.)

[3] Hinds, Henry, The coal deposits of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 11, p. 158 [1912].

[4] Idem, p. 159.

COOPER COUNTY.

Nearly all of the townships of Cooper County contain cannel and bituminous coal in pockets, in some of which the coal is 30 or more feet thick.

CRAWFORD COUNTY.

Many small pockets of coal occur in Crawford County between Sligo and Keysville in T. 36 N., R. 4 W. There are pockets in the west half of sec. 19 (location 1) reported by Winslow as 40 feet thick; in the NE. ¼ SE. ¼ sec. 21 (location 2); in the NE. ¼ NW. ¼ sec. 29 (location 3); and in the NE. ¼ sec. 30 (location 4). None of them are believed to be of much value.

JASPER COUNTY.

Smith and Siebenthal[1] report: "In many of the hollows and sink holes eroded in the surface of the Boone and filled by Cherokee, coal pockets were found, the thickness of coal accumulated being in places very great. The coal is commonly cannel." Most of the described deposits are only a few feet in diameter and 2 to 8 feet thick.[2]

LINCOLN COUNTY.

Coal pockets of great thickness occur in Lincoln County. Several of them on the headwaters of Coon Creek have attracted much attention in the past and have been mined a little.[3]

MILLER COUNTY.

Several pockets of cannel coal have been encountered in wells in Miller County, but none has yet been mined. In T. 41 N., R. 16 W., 3 feet of cannel at a depth of 19 feet is reported from the SE. ¼ sec. 2 (location 1); 3 feet in the well at the schoolhouse in the center of sec. 11 (location 2); 12 to 14 feet at a depth of 8 feet on the Joseph Garden place in the south center of the NW. ¼ NE. ¼ sec. 3 (location 3); and a bed at 48 feet in the well near the center of sec. 11. In the same township cannel coal is exposed in the stream banks in the SW. ¼ NW. ¼ sec. 3 (location 4) and in the bed of a small stream in the center of the W. ½ SW. ¼ sec. 2, where a 40-foot shaft is all in cannel coal except 1½ feet of carbonaceous shale.[4]

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[1] Smith, W. S. T., and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Joplin district folio (No. 148), pp. 19–20, 1907.

[2] Hinds, Henry, Missouri Bur. Geology and Mines, 2d ser., vol. 11, p. 215 [1912].

[3] Idem, p. 253.

[4] Ball, S. H., and Smith, A. F., Geology of Miller County: Missouri Bur. Geology and Mines, 2d ser., vol. 1, p. 103, 1903.

MONITEAU COUNTY.

All of the coal in Moniteau County occurs in pockets, of which at least three are being mined.

The Monarch Coal & Mining Co. is mining cannel in sec. 15, T. 43 N., R. 16 W. (location 1), by stripping and by drifts. The stripped pit shows 30 feet of cannel coal, overlain by 5 feet of poor bituminous coal. A 90-foot shaft at the east end of the open cut is in cannel, and a tunnel driven 140 feet south from the foot of the shaft is reported to be all in cannel. In the open cut the coal dips 45°, but at the end of the tunnel or drift it lies flat. The pocket is about 400 feet long by 150 to 200 feet wide, and the cannel is estimated to be 45 feet thick where the dips are absent. The total contents of this pocket do not appear to be over 75,000 tons.

At the Newkirk mine, in the NW. ¼ SE. ¼ sec. 12, T. 44 N., R. 17 W. (location 2), the shaft is 110 feet deep. Coal was struck at 45 feet and continued for 65 feet to the bottom of the shaft. Drifts have been cut to the north and the south, and from them 30 feet of coal has been mined. The coal pitches toward the center from all sides and is well jointed and slickensided and of fair quality, though high in ash. The deposit is estimated to be about 285 feet long by 100 feet wide.

Two shafts have been sunk by C. P. Keller in the NE. ¼ sec. 22, T. 43 N., R. 16 W. (location 3). One of them struck 6 feet of bituminous coal at 20 feet and 7½ feet of (cannel?) coal 24 feet lower.

The Rohrback & Rowlin Mining Co. sunk a 50-foot shaft in the S. ½ SE. ¼ sec. 23, T. 45 N., R. 15 W., disclosing 10 to 15 feet of cannel coal over 10 feet of poor bituminous coal and under 10 feet of bituminous shale. The coal is said to slack badly and to have a high percentage of ash. The pocket measured about 125 by 80 feet.[1]

MORGAN COUNTY.

The pockets in Morgan County have been worked to some extent and have figured in a number of real estate deals involving considerable areas of land. The Stover mine shows an interesting example of a pocket of bituminous coal 70 feet thick. The Hubbard & Moore mine in the SW. ¼ SW. ¼ sec. 22, T. 43 N., R. 18 W. (location 1), is working a very irregular deposit about 20 feet thick, of which the upper 15 feet is cannel and the lower 5 feet bituminous coal. Black shale occurs both above and below the coal. Where obtained the coal dips 32° to 33° but flattens out in a short distance. In the NW. ¼ SE. ¼ sec. 5, T. 42 N., R. 17 W. (location 2), is a 12 to 15 foot bed

[1] Van Horn, F. B., The geology of Moniteau County: Missouri Bur. Geology and Mines, 2d ser., vol. 3, pp. 65–68, 78–79, 1905. Hinds, Henry, Missouri Bur. Geology and Mines, 2d ser., vol. 11, pp. 307–308 [1912].

of coal, of which the upper half, or a little more, is cannel. Mining has been carried on in a small way at many places in the county.[1] In a pocket being worked for coal and clay by the Ouachita Coal & Clay Products Co. in the SW. ¼ SW. ¼ sec. 22, T. 43 N., R. 18 W. (location 3), there is exposed 15 feet of alternating layers of bituminous and cannel coal. Pockets of cannel that have been worked out are 1½ miles east of Versailles at the Martin mine (location 4) in the SW. ¼ SE. ¼ sec. 5, T. 42 N., R. 17 W.; at the McClure bank (location 5) a mile north of Martins; and at the Price bank (location 6) half a mile north of the McClure bank.[2]

SALINE COUNTY.

A pocket of bituminous and cannel coal 22 feet thick was formerly worked at Napton, Saline County.

ARKANSAS.

Extending northwestward from Camden, Ouachita County, Ark., is a small area of typical brown subcannel, which has been tested for oil and gas production with very favorable results (pp. 38, 47). The coal bed has been traced from about 2 miles northwest of Camden for 13 miles to the northwest and has been opened and mined in a small way at a number of places. Among these openings, in which the coal ranges from 3 to 6 feet in thickness, are the following: Brown mines, east side of sec. 12, T. 13 S., R. 18 W., coal 3 to 3½ feet; Williams mine, north side of sec. 11, T. 13 S., R. 18 W., coal 3½ feet; Demsey mine, NE. ¼ SW. ¼ sec. 25, T. 12 S., R. 18 W., coal 3 feet; two drifts near center of sec. 14, T. 12 S., R. 18 W., to which a 3-mile railroad spur was built, coal reported 5 to 6 feet; mine in NE. ¼ sec. 12, T. 12 S., R. 18 W., opened before 1860, coal 3 feet 6 inches to 6 feet; mines in secs. 7 and 19, T. 12 S., R. 17 W., coal 3 to 3½ feet; Bratt shaft, sec. 2, T. 13 S., R. 18 W., 3 feet of coal at 40 feet.[3]

Physically the Camden coal, as it comes from the mine,[4] is

brownish black and compact and has a generally uniform even texture and structure. Occasionally fragments of lignite with clearly marked woody structure may be seen. It has an uneven conchoidal fracture. It is soft but not friable, that is, it may be easily mined with the pick and may be cut with a knife as readily as compact dry clay, but will not crumble between the fingers. When cut or scratched with a knife it shows a shiny or oily streak. Upon being exposed to dry air the coal contracts and cracks both along the bedding and at right angles to it so that fragments may be broken by the hand, but the mass does not fall to pieces. The coal is then blacker and harder than when fresh

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[1] Marbut, C. F., The geology of Morgan County: Missouri Bur. Geology and Mines, 2d ser., vol. 7, pp. 79–86 [1908].

[2] Hinds, Henry, Missouri Bur. Geology and Mines, 2d ser., vol. 11, p. 318 [1912].

[3] Taff, J. A., Preliminary report on the Camden coal field of southwestern Arkansas: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 323–324, 1900.

[4] Idem, p. 325.

and the streak or powder is more nearly black. On being exposed for a short time to the repeated action of rain, dew, and snow, however, it will disintegrate into small particles.

From this description the coal is evidently of lignite rank, but so far as tested it appears to give a higher candlepower gas than other lignites. Chemically, as shown by the analyses (Nos. 13–18, p. 20), it contains from 32 to 38 per cent of water when fresh. In dry air the moisture will be reduced to 9 to 11 per cent, but this will be reincreased to 20 to 22½ per cent if the coal is submitted to saturated air. The volatile matter in the fresh coal is 32 to 36 per cent and 44 to 46 per cent in the air-dried coal; and the fixed carbon in the fresh coal is 17 to 23 per cent and 29 to 33 per cent in the air-dried coal. The ash remains from 7.5 to 11 per cent in the fresh coal and the sulphur 0.5 per cent or less in the fresh material.

This coal was tested by the Pittsburgh Testing Laboratory (Ltd.). The average result of 10 tests, at a temperature of 1,800° to 2,000° F. was a yield of 11,386 cubic feet of 22.3 candlepower gas. How this compares with other coals is shown in the table on pages 37–38.

David White,[1] who visited the field, describes as follows the two stills that were in operation:

The commercial untilization of the lignite from the Camden field is somewhat unique, for although it is employed to a limited extent for local steam-boiler fuel and on the locomotives of the branch railroads coming to the sawmills and mines about Lester, the principal use of the coal appears to be for its distillation products. The best massive brown lignite, essentially "amorphous" and free from bedding, is that most sought for distillation. Such lignite is said to yield as high as 38 gallons of oil per ton, though the average oil production from the lignite as it is mined and distilled approximates 25 gallons per ton. Occasionally lignite which yields as low as 10 gallons per ton is dug at some of the mines in the field. At the time of the field examinations of the fuel by the writer the methods of distillation were still in an experimental stage. A small distillery or "oil mill" was in operation at the town of Camden and another one near Lester. The former had seven horizontal retorts, whereas the latter had only five in an inclined position and farther above the grate. The Lester mill had a capacity of two tons in 24 hours. For three or four hours the lignite in the retort was subjected to a temperature of about 400° F., after which it was advanced for a time to a temperature of about 700°, and finally to 1,200° or 1,300° F., eight or nine hours being required for the complete run. Some of the oil is given off at a temperature of about 400° F., different oils being yielded at different temperatures, those distilling later at the higher temperatures being regarded as best. Likewise, the higher temperatures appear to yield by-products more tarlike and differing in other respects. The brown canneloid is said to yield a lighter-colored oil.

The distillates are said to be used in the rubber industry, in soap making, in paints, and in various proprietary preparations. The residual cinder can hardly be called coke, although often on withdrawing the charge there appears to be a recondensation at the back end of the retort which results in small pieces of completely fused coke, silvery in luster and stalactytic in sculpture,

[1] White, David, and Thiessen, Reinhardt, Bur. Mines Bull. 38, p. 18, 1913.

though spongy and friable. The higher-grade carbon or cinder derived from the more typical canneloid lignite, after having been ground at the mill, has been shipped to one of the eastern cities, where it was experimentally tried in the manufacture of paint. The small pieces of wood and stem are occasionally found with structure preserved as charcoal among the lumps of lignitic cinder.

TEXAS.[1]

Probably the largest deposit of cannel coal in the United States is in Webb County, Tex., a few miles above Laredo, near the Rio Grande. The coal occurs in Eocene rocks, apparently in beds such as commonly contain soft brown friable lignites, but it is a hard, lustrous, black coal, the beds yielding 75 per cent or more of lump coal by ordinary methods of mining. The coal stands shipping and storing like an ordinary bituminous coal. It differs physically from typical cannel coal in having a brighter luster, in being less massive, and in breaking down under the weather more readily than the Carboniferous cannels, although possibly not more readily than the average bituminous coal. Of the two beds now mined, the lower is more like cannel. In the mine the coal shows one prominent cleavage (N. 30° E.) closely spaced.

There are two principal beds, about 90 feet apart, and several minor beds, all of the same general character except as the percentage of ash makes some of them bony coals. The upper or Santo Tomas bed has been traced in workable thickness 25 miles or more along the river front. It is 24 to 34 inches thick, this measurement including commonly 2 to 4 inches of bone or shale in the middle, and is underlain by 2 to 14 inches of bone. The lower or San Pedro bed is 22 to 24 inches thick at Dolores, is thin or absent at Santo Tomas, and is reported to be 4 feet thick at the mouth of Llave Creek. Both coals have poor roofs, commonly of clay, and clay floors, inclined to creep, drawbacks that add materially to the cost of mining.

Three mines are now in operation, the Santo Tomas, of the Santo Tomas Coal Co., and the Darwin and Dolores mines of the Cannel Coal Co. These mines are at towns bearing the names of the mines, 23 to 26 miles above Laredo, with which they are connected by the Rio Grande & Eagle Pass Railway.

The upper coal crops out above the bottoms of the Rio Grande for many miles up the river from Dolores. The beds dip about 2° NE. This dip carries the coal beds to a depth of several hundred feet under the high bluff that stands a short distance back from the river. One fault of 3 to 4 feet throw breaks the upper bed at the Dolores mines but does not break the lower bed. At the Santo Tomas

[1] This section was rewritten Aug. 16, 1917, and inserted in page proof after the author had returned from the Laredo coal field, which he studied in detail. This field will be described more fully in a forthcoming report of the United States Geological Survey.

mine there are areas where the coal is much broken by fault slips, the thickness of the bed commonly changing abruptly on the two sides of these breaks. These slips, taken in connection with the abundant slickensides in the roof clay, have led the writer to infer that this area has been subject to slight earth pressure and movement, and that because of the large proportion of clay in the section, this pressure, instead of being taken up by massive beds of sandstone, as it commonly is in Carboniferous rocks, was resisted mainly by the coal beds, which were thus raised to the rank of bituminous coals. The dry atmosphere of the region may have reduced the content of moisture in the coal, which is rather dry. Ten recent analyses of the Santo Tomas coal, made in connection with its purchase by the Government for use at Fort MacIntosh, show that it contains 4.45 per cent of moisture as received, and that the dry coal contains 42.5 per cent of volatile matter, 36.8 per cent of fixed carbon, 20.58 per cent of ash, and 2.87 per cent of sulphur, and has a heat value of 10,889 British thermal units as received, or 14,349 British thermal units moisture and ash free.

Tests of this coal for its content of oil gave 52.2 gallons per ton, or 20.2 per cent by weight, with a specific gravity of 0.938 at 60° F. This area would therefore seem to be a favorable place for establishing a distillation plant, because of the large quantity of coal already found. The coal is now used on seven railroads—the Artesian Belt; San Antonio, Uvalde & Gulf; Rio Grande & Eagle Pass; International & Great Northern; Abilene & Southern; Coahuila and Zacatecas; and Mexican Government lines. It is shipped to Austin, San Antonio, Corpus Christi, and other places as a domestic fuel and is the principal steam coal of the surrounding region.

UTAH.

A bed of black subcannel (?) coal of subbituminous (?) rank, opened in the valley of North Fork of Virgin River in the Colob coal field at the Cannel King prospect, may be described as typical. The bed, whose extent is not known, contains 5 feet 6 inches of cannel overlain by 2 feet 6 inches of bituminous coal. The opening is in sec. 26, T. 39 S., R. 9 W.[1] The associated coal here is subbituminous, and the cannel has a slightly earthy appearance; otherwise it is a typical cannel coal in appearance and characteristics.[2] The analysis likewise indicates a typical cannel coal: The upper 2 feet carry 44.9 per cent of volatile matter, 28 per cent of fixed carbon, and 14.3 per cent of ash; and the lower 3½ feet carry 46.9 per cent of volatile matter, 22.4 per cent of fixed carbon, and 23.2 per cent of ash.

[1] Richardson, G. B., The Harmony, Colob, and Kanab coal fields, southern Utah: U. S. Geol. Survey Bull. 341, p. 394, 1900.

[2] White, David, and Thiessen, Reinhardt, Bur. Mines Bull. 38, p. 244–245, 1913.

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